The Facilitation of Mini and Small Hydropower in Switzerland: Shaping the Institutional Framework (with a Particular Focus on Storage and Pumped-Storage Schemes)

THÈSE N^{O} 5356 (2012)

PRÉSENTÉE LE 3 JUILLET 2012

AU COLLÈGE DU MANAGEMENT DE LA TECHNOLOGIE
CHAIRE LA POSTE EN MANAGEMENT DES INDUSTRIES DE RÉSEAU
PROGRAMME DOCTORAL EN MANAGEMENT DE LA TECHNOLOGIE

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

POUR L'OBTENTION DU GRADE DE DOCTEUR ÈS SCIENCES

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ÉCOLE POLYTECHNIQUE
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Suisse
2012

Summary

The electricity sector in Switzerland is undergoing important changes following the liberalisation process and the facilitation of renewable energy technologies. Furthermore, the phasing out of nuclear power will increase the demand for new domestic electricity generation. According to the Federal Energy Strategy 2050, additional generation will have to come from hydropower (currently 57% of Swiss electricity production), including small hydropower (currently 6%, i.e. 3.8 TWh).

The small hydropower technology, with an installed capacity between 100 kW and 10 MW (whereby 100 kW till 1 MW is considered to be mini hydropower), is a renewable energy technology (RET) which is well developed. However, the technology still requires further innovation to improve its environmental integration and reduce costs. Small hydropower (SHP) provides electricity with a high energy payback ratio and, generally, with lower production costs than other RETs, aside from large hydropower. SHP can be combined within multipurpose infrastructures such as drinking water and irrigation networks. The institutional framework of SHP is conditioned by multi-level (i.e., Federal, Cantonal and Communal) and cross-sectorial institutions (e.g., within the electricity and water sectors, spatial planning). SHP still has significant potential in Switzerland with the possibility of increasing the production of 2010 by 40-50% by 2050. However, SHP requires appropriate policy instruments for its development within a liberalised electricity market as it is, on average, not yet cost-competitive. In 2009, for example, a Federal feed-in remuneration scheme was introduced. To further develop the SHP potential, the institutional framework has still to evolve.

This research was aimed at identifying changes in the institutional framework in Switzerland which can contribute towards developing SHP and increasing the alignment between the technology and its institutions. To this end, the literature on co-evolution and the framework of coherence between institutions and technologies in the case of network industries, such as electricity, were used for the analysis. This thesis contributes towards further development of the coherence framework.

Policy instruments are identified that can support the development of SHP. Measures to simplify and harmonise administrative procedures are evaluated, even though their implementation remains difficult. A promising endeavour, however, is to reduce opposition, thus duration of procedures, by developing regional master plans and/or multi-criteria evaluations of projects at the very early project development phase. This enables the pursuit of projects for which all stakeholders are favourable to their realisation. Another required measure is guaranteeing the technical quality of plants which receive the feed-in remuneration by introducing a global efficiency criterion. Finally, other policy instruments are analysed such as green certificates, the feed-in remuneration scheme, and CO_2 credits, which will become necessary following the opening of new gas-fired plants.

The current institutional facilitation of RETs generating electricity focuses solely on quantity, i.e. kWh. It does not consider the need for flexible production and energy storage to deal with the intermittent generation of some RETs and to align the electricity demand and supply. This is not coherent. The institutional facilitation should take into account flexible production and energy storage, and thus specifically support technologies such as storage and pumped-storage SHP. This research investigated, using an explorative and bottom-up approach, the technical potential of small storage and pumped-storage plants by focusing on existing and planned reservoirs in order to reduce investment costs and environmental opposition. Eleven projects were identified in the Canton of

Valais. The potential in Switzerland is evaluated at roughly 200-300 MW for storage SHP plants (today 106 MW is used) and 70-150 MW for pumped-storage SHP plants (today 15 MW is used). In order to further develop this potential, which is complementary to the large storage and pumped-storage hydropower potential, some remuneration instruments are identified. The instruments include adapting the feed-in remuneration scheme to facilitate not only run-of-river plants, introducing requirements for ancillary services from RETs (in addition to large hydropower), and CO_2 credits and green certificates depending on the production profile (e.g., peak and off-peak).

The identified instruments lead to policy recommendations which would further facilitate the development of SHP in Switzerland, including storage and pumped-storage plants. In summary, the main findings of this research are four-fold:

- The institutional framework has to further evolve to be aligned with the small hydropower technology.
- The institutional facilitation of renewable energy technologies must not only focus on the quantity of energy, i.e. kWh, but also on the "quality", such as flexible production and energy storage.
- Storage and pumped-storage small hydropower could play an important role in producing distributed peak and balancing electricity and in contributing to distributed energy storage. Its technical potential in Switzerland is significant enough to shape the institutional framework adequately.
- The coherence framework offers a very useful lens to analyse technological and institutional changes in the network industries. However, it still needs to be improved to become more robust and less conceptual.

Keywords: mini and small hydropower, institutional framework, policy instruments, storage and pumped-storage, electricity sector, co-evolution and coherence, Switzerland

Résumé

Le secteur de l'électricité en Suisse est soumis à des changements importants suite au processus de la libéralisation et à la promotion des énergies renouvelables. En outre, la sortie progressive de l'énergie nucléaire va augmenter la demande pour une nouvelle production d'électricité domestique. Selon la Stratégie énergétique 2050 du Conseil Fédéral, une part de la production supplémentaire devra provenir des centrales hydrauliques (actuellement 57% de la production suisse d'électricité), y compris des petites centrales hydrauliques (actuellement 6%, soit 3.8 TWh).

Les petites centrales hydrauliques (PCH), d'une capacité installée comprise entre 100 kW et 10 MW (100 kW à 1 MW étant considéré comme mini hydraulique), utilisent une technologie d'énergie renouvelable qui est bien développée. Cependant, la technologie nécessite encore davantage d'innovation pour améliorer son intégration dans l'environnement et pour réduire des coûts. Les PCH produisent avec un ratio d'efficience énergétique élevée et, généralement, avec des prix de revient inférieurs à ceux des autres centrales fonctionnant avec des sources d'énergie renouvelable, hormis la grande hydraulique. Les PCH peuvent être intégrées au sein d'infrastructures à buts multiples telles que dans des réseaux d'eau potable et d'irrigation. Le cadre institutionnel affectant les PCH est conditionné par les différents niveaux administratifs (c.-à-d. fédéral, cantonal et communal) et par des institutions de plusieurs domaines (par exemple, du secteur de l'électricité, des domaines de l'eau et de l'aménagement du territoire). Les PCH ont encore un potentiel important en Suisse avec la possibilité d'augmenter la production de 2010 de 40-50% d'ici 2050. Toutefois, les PCH nécessitent en général des instruments institutionnels appropriés pour leur développement au sein du marché libéralisé de l'électricité. Ceci vient du fait que les PCH, en général, ne produisent pas encore à un prix compétitif. En 2009 par exemple, une rétribution à prix coûtant (RPC) a été introduite. Pour développer davantage le potentiel des PCH, le cadre institutionnel doit encore évoluer.

Cette recherche visait à identifier des changements du cadre institutionnel en Suisse qui peuvent contribuer au développement des PCH et à augmenter l'alignement entre la technologie et ses institutions. A cette fin, la littérature de la coévolution et le cadre de la cohérence entre les institutions et les technologies dans le cas des industries de réseau, comme l'électricité, a été utilisée pour l'analyse. La thèse contribue au développement du cadre de la cohérence.

Des instruments institutionnels, qui peuvent soutenir le développement des PCH, sont identifiés. Des mesures visant à simplifier et à harmoniser les procédures administratives sont évaluées, même si leur mise en œuvre reste difficile. Cependant, une option prometteuse est de réduire les oppositions, et ainsi la durée des procédures, en élaborant des plans directeurs régionaux et / ou des évaluations multicritères de projets en phase de développement précoce. Cela permet de poursuivre uniquement des projets pour lesquels toutes les parties prenantes sont favorables à leur réalisation. Une autre mesure requise est de garantir la qualité technique des centrales qui reçoivent la RPC par l'introduction d'un critère d'efficience énergétique global. Enfin, d'autres instruments institutionnels sont analysés tels que les certificats verts, la RPC, et les crédits CO_2 qui seront nécessaire suite à l'ouverture de nouvelles centrales au gaz.

La promotion actuelle des énergies renouvelables pour la production d'électricité se concentre uniquement sur la quantité, c.-à-d. des kWh. Elle ne considère pas la nécessité d'une production flexible et du stockage d'énergie pour faire face à la production intermittente de certaines sources d'énergie renouvelable, ainsi que l'alignement de la demande d'électricité et de l'approvisionnement. Ce n'est pas cohérent. La promotion institutionnelle devrait prendre en compte la production flexible et le stockage d'énergie, et donc spécifiquement soutenir les technologies telles que la petite hydraulique d'accumulation et à pompage-turbinage. Cette recherche a étudié avec une approche exploratoire le potentiel technique des PCH d'accumulation et à pompage-turbinage en se concentrant sur des réservoirs existants et prévus afin de réduire les coûts d'investissement et l'opposition environnementale. Onze projets ont été identifiés dans le Canton du Valais. Le potentiel en Suisse est évalué à environ 200-300 MW pour les PCH d'accumulation (aujourd'hui exploité à 106 MW) et 70-150 MW pour les PCH à pompage-turbinage (aujourd'hui exploité à 15 MW). Afin de développer ce potentiel, qui est complémentaire au potentiel des grandes centrales hydrauliques d'accumulation et à pompage-turbinage, différents instruments de rémunération sont identifiés. Les instruments comprennent l'adaptation de la RPC afin de promouvoir non seulement des centrales au fil de l'eau, l'introduction d'exigences pour les services systèmes venant des sources d'énergie renouvelable (en plus des grandes centrales hydrauliques), et des crédits CO_2 et des certificats verts en fonction du profil de production (par exemple, la différentiation entre heures de pointe et creuses).

Les instruments identifiés mènent à des recommandations concernant le cadre institutionnel afin de promouvoir le développement des PCH en Suisse, y compris les centrales d'accumulation et à pompage-turbinage. En résumé, les points clés de cette recherche sont les suivants:

- Le cadre institutionnel doit continuer à évoluer pour être aligné avec la technologie des petites centrales hydrauliques.
- La promotion des énergies renouvelables ne doit pas seulement se concentrer sur la quantité d'énergie, c.-à-d. des kWh, mais aussi sur la «qualité», tels que la production flexible et le stockage d'énergie.
- Les petites centrales hydrauliques d'accumulation et à pompage-turbinage pourraient jouer un rôle important dans la production d'électricité décentralisée de pointe et de réglage, et contribuer au stockage d'énergie décentralisé. Le potentiel technique en Suisse est suffisamment important pour adapter le cadre institutionnel de manière adéquate.
- Le cadre de cohérence propose une perspective très utile pour analyser les changements technologiques et institutionnels dans les industries de réseau. Cependant, il doit encore être amélioré pour devenir plus robuste et plus concret.

Mots-clés: mini et petites centrales hydrauliques, cadre institutionnel, accumulation et pompage-turbinage, secteur de l'électricité, coévolution et cohérence, Suisse

Zusammenfassung

Der Schweizer Stromsektor ist durch den Prozess der Liberalisierung und durch die Förderung der erneuerbaren Energien einem tief greifenden Wandel ausgesetzt. Zudem wird der geplante Ausstieg der Schweiz aus der Kernenergie die Nachfrage nach zusätzlicher und inländischer Stromerzeugung erhöhen. Gemäss der Energiestrategie 2050 des Bundesrates soll ein Teil der zusätzlichen Stromproduktion aus Wasserkraft stammen (derzeit 57% der Produktion in der Schweiz), einschließlich der Kleinwasserkraft (derzeit 6%, d.h. 3.8 TWh).

Kleinwasserkraftwerke (KWKW), deren installierte Leistung von 100 kW bis 10 MW reicht (wobei Kraftwerke mit 100 kW bis 1 MW als Miniwasserkraftwerke gelten), produzieren Strom mittels einer Technologie, welche eine erneuerbare Energiequelle nutzt und heute gut entwickelt ist. Allerdings erfordert die Technologie noch weitere Innovationen, damit ihre Integration in die Umwelt verbessert und die Kosten gesenkt werden können. KWKW haben eine hohe Energierückgewinnungsrate und weisen generell niedrigere Produktionskosten auf als andere Kraftwerke, die mit erneuerbaren Energien betrieben werden, (abgesehen von der Grosswasserkraft). KWKW können innerhalb von Mehrzweckinfrastrukturen mit einer Trinkwasserversorgung oder einem Bewässerungssystem kombiniert werden. Der institutionelle Rahmen für KWKW wird von mehrstufigen Verwaltungsebenen (d.h. Bund, Kanton und Gemeinden) und von branchenübergreifenden Verbandsebenen (z. B. Strom- und Wassersektor) bestimmt. KWKW haben noch ein wichtiges Potenzial in der Schweiz, so dass die Produktion des Jahrs 2010 bis 2050 um 40-50% erhöht werden könnte. Allerdings erfordern KWKW für ihre Entwicklung im liberalisierten Strommarkt geeignete institutionelle Instrumente, da die Technologie im Allgemeinen noch nicht zu wettbewerbsfähigen Preisen produzieren kann. In diesem Zusammenhang wurde zum Beispiel im Jahr 2009 eine kostendeckende Einspeisevergütung (KEV) eingeführt. Damit allerdings das KWKW-Potenzial weiter ausgeschöpft werden kann, muss sich der institutionelle Rahmen noch weiter entwickeln.

Die vorliegende Forschungsarbeit hatte zum Ziel, Veränderungen des institutionellen Rahmens in der Schweiz zu identifizieren, welche dazu beitragen können, die Kleinwasserkraft weiter auszubauen und die Institutionen besser auf die Technologie abzugleichen. Für die Analyse wurden die Literatur der Ko-Evolution und das Model der Kohärenz zwischen Institutionen und Technologien im Fall von Netzwerkindustrien (z.B. Strom) verwendet. Diese Arbeit leistet einen Beitrag zur Weiterentwicklung des Kohärenzmodels.

Institutionelle Instrumente, welche den Bau von KWKW fördern können, werden identifiziert. Massnahmen zur Vereinfachung und Harmonisierung der administrativen Verfahren werden ausgewertet, obwohl ihre Umsetzung schwierig bleibt. Ein vielversprechender Ansatz ist indessen die direkte Verringerung des Widerstands gegen Projekte, und damit die Verkürzung der Verfahrensdauer, mittels Ausarbeitung von regionalen Richtplänen und/oder Multikriterienbewertungen von Projekten in der frühen Entwicklungsphase. Dadurch werden nur Projekte weiter verfolgt, deren Verwirklichung alle Beteiligten befürworten. Eine weitere erforderliche Maßnahme ist das Gewährleisten der technischen Qualität von Anlagen, welche die kostendeckende Einspeisevergütung erhalten, mittels der Einführung eines globalen Effizienzkriteriums. Schließlich werden andere institutionelle Instrumente analysiert, wie grüne Zertifikate, die kostendeckende Einspeisevergütung, und CO_2-Kredite, die für neue Gaskraftwerke erforderlich werden.

Die aktuelle institutionelle Förderung der erneuerbaren Energien zur Stromerzeugung konzentriert sich nur auf die Quantität, d.h. kWh. Die Förderung berücksichtigt nicht die Notwendigkeit einer flexiblen Produktion und der

Speicherung von Energie, um der unregelmässigen Produktion einiger erneuerbaren Energien Rechnung zu tragen und die Stromproduktion und –nachfrage aufeinander abzugleichen. Dieses Vorgehen ist nicht kohärent. Die institutionelle Förderung sollte eine flexible Produktion sowie die Energiespeicherung berücksichtigen, und somit gezielt Technologien wie Speicher- und Pumpspeicherkleinwasserkraft unterstützen. Die vorliegende Forschungsarbeit untersuchte mit einem Bottom-up-Ansatz das technische Potenzial von Speicher- und Pumpspeicher-KWKW. Dabei wurde der Fokus auf bestehende und geplante Reservoirs gelegt, weil dadurch die Investitionskosten und die Anzahl möglicher Einsprachen aus Umweltschutzgründen reduziert werden können. In diesem Rahmen wurden im Kanton Wallis elf Projekte identifiziert. Weiter wird das Potenzial für Speicher-KWKW in der Schweiz auf rund 200-300 MW (heute 106 MW genutzt) und für Pumpspeicher-KWKW auf 70 bis 150 MW (heute 15 MW genutzt) abgeschätzt. Damit dieses Potenzial, welches das Speicher- und Pumpspeicher-Grosswasserkraftpotenzial ergänzt, weiter entwickelt wird, werden verschiedene Vergütungsinstrumente identifiziert. Diese Instrumente umfassen die Anpassung der kostendeckenden Einspeisevergütung, damit nicht nur Flusskraftwerke gefördert werden, die Einführung von Vorschriften für Systemdienstleistungen von Kraftwerken, welche erneuerbare Energien nutzen (zusätzlich zur Grosswasserkraft), sowie CO_2-Kredite und grüne Zertifikate in Abhängigkeit vom Produktionsprofil (z. B. Spitzen- oder Bandstrom).

Die identifizierten Instrumente führen zu Empfehlungen betreffend der Anpassung des institutionellen Rahmens, damit die Kleinwasserkraft in der Schweiz einschliesslich Speicher- und Pumpspeicheranwendungen weiter ausgebaut werden kann. Zusammenfassend sind die wichtigsten Ergebnisse dieser Forschungsarbeit die Folgenden:

- Der institutionelle Rahmen muss sich weiter entwickeln, damit dieser besser mit der Technologie der Kleinwasserkraft abgeglichen ist.
- Die institutionelle Förderung der erneuerbaren Energie sollte sich nicht nur auf die Quantität der Stromproduktion konzentrieren, d.h. kWh, sondern auch auf die „Qualität“ wie z.B. die Flexibilität der Produktion und die Möglichkeiten der Energiespeicherung.
- Speicher- und Pumpspeicherkleinwasserkraft könnten eine wichtige Rolle bei der dezentralen Spitzen- und Regelstromerzeugung und der dezentralen Energiespeicherung spielen. Das technische Potenzial in der Schweiz ist bedeutend genug, um den institutionellen Rahmen entsprechend anzupassen.
- Das Kohärenzmodell bietet eine wertvolle Perspektive, um die technologischen und institutionellen Veränderungen in den Netzwerkindustrien zu analysieren. Das Modell muss jedoch weiter verbessert werden, um robuster und weniger konzeptionelle zu sein.

Schlüsselwörter: Kleinwasserkraft, institutioneller Rahmen, Speicher- und Pumpspeicherwerke, Stromsektor, Koevolution und Kohärenzmodel, Schweiz

Acknowledgment

My particular thanks go to Prof. Matthias Finger (EPFL) and Prof. Hans Björn Püttgen (EPFL). I thank Prof. Finger for the initial offer of a PhD with his Chair, for the inspiring discussions on network industries, for his conceptual and broad approach to problems and for his feedback during the research. I thank Prof. Püttgen for his pragmatic advice regarding the energy sector and his feedback regarding the research, for involving me in some very interesting projects and for co-funding the PhD research.

I thank Dr. Marc Laperrouza (EPFL/UNIL) for his practical advice regarding the research, for teaching me how economists think and for our many discussions beyond this research topic. I also thank Dr. Massimiliano Capezzali (EPFL) for his availability and technical advice, as well as our discussions of issues outside of the energy sector.

My distinct gratitude goes to EOS Holding for co-funding this research and to its committee for their valuable feedback during the research. I thank especially Jean-Marie Rouiller for his advice as President of ADUR and for the contacts he provided, as well as Dr. Alain Sapin (Groupe E) for being part of the examination jury.

I thank also Prof. Anton Schleiss (EPFL) for his technical advice during this research and for being part of the examination jury. I thank Prof. François Avellan (EPFL) for his teaching on turbine hydraulics and for his technical advice. I thank Prof. Rolf Künneke for advice on the theoretical framework and for being part of the examination jury. And I thank Prof. Cécile Münch-Alligne (HES-SO) for the several discussions on turbines and the development of small hydropower.

My distinct thanks goes to Carol Hemund (University of Bern), the only other PhD student in Switzerland working on small hydropower, with whom I could often discuss this research.

Among the practitioners, I thank Dr. Philippe Heller (e-dric) for the collaboration on real projects and for the discussion on the assessment methodology. I thank Vincent Denis (Mhylab) for his advice in the early stages of the research which contributed towards its structure, as well as for his contacts.

Within the public administration, I thank especially Bernhard Hohl (SFOE) for his feedback and comments on the research. I thank Amadée Truffer (Canton du Valais) for his advice concerning the Canton of Valais.

Many thanks go to all the interviewed persons for their time, knowledge and opinions.

I thank Johannes Manser (ETHZ) for integrating some questions related to this research in the survey he produced. I thank Benoît Mailler (EPFL/e-dric) for his work on a concrete project of storage and pumped-storage small hydropower.

I thank Christof Duthaler (Swissgrid/EPFL) and Ralf Dyllick-Brenzinger (EPFL) for the discussions on the electricity and energy sectors which contributed towards the shaping of this research. I thank my colleagues at the Chair MIR and the Energy Center for the work environment they provided for this research.

Finally, my special thanks are for my wife who reviewed my English grammar and made me aware of when my writing missed steps that my thoughts had already taken.

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Glossary

ADUR	Association Des Usiniers Romands
ARE	Federal Office for Spatial Development
CDM	Clean Development Mechanism
CHF	Swiss Franc
CO_2	Carbon dioxide
DSO	Distribution System Operator
EAWAG	Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz
EPFL	Ecole Polytechnique Fédérale de Lausanne
ESHA	European Small Hydropower Association
ETHZ	Eidgenössische Technische Hochschule Zürich
ETS	Emission Trading Scheme
FIR	Feed-In Remuneration
FIT	Feed-In Tariff
FOEN	Federal Office for the Environment
GCC	Gas-fired Combined Cycle
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
ICT	Information and Communication Technology

ISKB	Interessenverband Schweizerischer Kleinwasserkraft-Besitzer
MHP	Mini Hydropower
MKF	“Mehrkostenfinanzierung”
NGO	Non-Governmental Organisation
NIE	New Institutional Economics
OIE	Old Institutional Economics
PPP	Public-Private-Partnership
RES	Renewable Energy Source
RET	Renewable Energy Technology
S&P/S-SHP	Storage and Pumped-Storage Small Hydropower
SFOE	Swiss Federal Office of Energy
SHP	Small Hydropower
TCE	Transaction Cost Economics
TGC	Tradable Green Certificate
TSO	Transmission System Operator
VAT	Value Added Tax
WFD	Water framework Directive

1. Introduction

Mini and small hydropower plants are renewable energy sources producing electricity with high efficiency and very low greenhouse gas emissions. In Switzerland, aside from large hydropower plants, they contribute the most to the domestic electricity production from renewable energy sources (RES). The mini and small hydropower technologies are well developed. However, in order to further unlock their potential, the institutional framework[1] has to further evolve taking into account the context of the liberalisation in the electricity sector and the Swiss renewable energy targets.

Whilst considering the dynamics in the Swiss electricity sector and the latest energy policy developments regarding the phasing out of nuclear power, this research aims to contribute towards the institutional facilitation[2] of mini and small hydropower in Switzerland. A particular focus is given to storage and pumped-storage schemes.

Due to their very similar institutional framework and policy instruments[3], this thesis considered mini and small hydropower together. However, only the term small hydropower (SHP) is used, with exceptions when the research specifically concern mini hydropower (MHP)[4].

This Chapter contains the problem statement which defines the research question and is followed by the motivation for this PhD research. Section 1.3 introduces the research objective, results and contribution to the literature. The structure of the thesis is explained along with the research design and the unit of analysis is defined. Finally, the methodology for the research is described.

1.1 Problem statement

In Switzerland, the Federal energy policy includes targets regarding the increase of electricity production from renewable energy technologies (RETs), including hydropower (see Chapter 2). The Federal government and parliament decisions to phase out from nuclear power following the Fukushima accident are leading to RET production target increases. In addition, several Swiss cities have committed to their own targets regarding RETs for their own electricity supply. Therefore, the importance of RETs within the Swiss electricity mix is increasing.

Aside from large hydropower, small hydropower is today's RET contributing the most to the Swiss electricity production with about 6% (see Chapter 4). SHP currently belongs to the RETs institutionally facilitated (e.g., feed-in remuneration; see Chapter 5). SHP still has significant unused technical potential. Its energy payback ratio is significantly higher and the production costs generally lower than other RETs. SHP can be part of multipurpose infrastructures combined with, for example, drinking water networks. The technology is well developed, but

[1] The word "institutional" is defined as *"relating to or constituting or involving an institution"* (http://wordnetweb.princeton.edu/perl/webwn?s=institutional). Institutions in this research are defined according to North as the rules of the game (see Chapter 3). Institutional framework refers to the set of informal and formal institutions (see also (Figueira and Parker, 2011: 501)).

[2] Facilitation is defined as the *"act of assisting or making easier the progress or improvement of something"* (http://wordnetweb.princeton.edu/perl/webwn?s=facilitation).

[3] Policy instruments are defined as *"the method or mechanism used by government, political parties, business or individuals to achieve a desired effect, through legal or economic means"* (http://www.eionet.europa.eu/gemet/concept?ns=1&cp=6373). More information in Section 5.2.2.

[4] SHP having an installed capacity below 10 MW and MHP having an installed capacity below 1 MW. For more on the definitions of MHP and SHP, see Section 4.1.1.

requires an adequate institutional framework to maximize its potential under economically viable and ecologically acceptable conditions. Therefore, institutions need to continue to evolve to be aligned with the SHP technology.

The alignment between institutions and technologies has been studied within the literature on co-evolution between institutions and technologies in the case of network industries and, in particular, by the coherence framework (see Chapter 3). As SHP is part of the electricity network industry this literature is relevant. The literature takes into account technological and institutional changes and their co-evolution. The liberalisation process in the network industries is such an institutional change affecting technologies. The framework intends to evaluate the coherence between the institutions and technologies taking into account the characteristics of network industries. There is no such literature applied to SHP.

The main research question is thus **how can institutions and technology be better aligned in the case of SHP?** The answers will lead to identification of new and adapted policy instruments which will further facilitate SHP in Switzerland.

During the research, two research sub-questions emerged. The current RET facilitation in Switzerland focuses only on increasing the quantity of renewable electricity, but does not take into account "quality" such as the alignment of supply and demand, the need for flexible and peak production, and the need for energy storage. The institutional facilitation is thus not coherent with its technological consequences such as the increased intermittency in electricity production from RETs such as photovoltaic and wind power. The facilitation of SHP does not consider the role that SHP could have for flexible production and energy storage with storage and pumped-storage schemes. Such schemes could contribute to the alignment of institutions and technologies within the facilitation of RETs and should therefore be included in the SHP facilitation. A study of the technical potential and the institutional feasibility of such schemes in Switzerland has yet to be done.

The research sub-questions are thus: **1) what is the potential of storage and pumped-storage SHP plants in Switzerland? and 2) how do institutions need to further evolve to enable the development of such plants?**

Finally, it has to be highlighted that this research does not discuss in detail the environmental integration of SHP and its development within spatial planning. This is done within the PhD research of Carol Hemund at the Oeschger Center at the University of Bern which took place during the same period as this PhD research (see Section 4.2.2). Both authors coordinated their research.

1.2 Motivation

This PhD research was triggered by the author's interest in small hydropower and, in a broader sense, network industries. In 2006, a Masters in Civil Engineering and a degree in the Management of Technology and Entrepreneurship were completed at the EPFL with energy and water as the main study interests. The author's master thesis included a general paper on mini hydropower (Crettenand, 2006b), and a feasibility study and business plan for a mini hydropower project in the Canton of Bern (Crettenand, 2006a), both of which were conducted at the Laboratory of Hydraulic Constructions (LCH) and the Chair of Management of Network Industries (MIR).

Time at EPFL was followed by a year of work as a Water and Sanitation Manager in Madagascar for the emergency and rehabilitation NGO MEDAIR. The author's interest in Africa had already started during his time in grammar school with a well drilling and school project in Burkina Faso[5]. Mainly in Madagascar, but also in Kenya and Tanzania, the author saw the potential for SHP as RET for distributed electricity production. In the African

[5] For more information, see www.guinkouma.org

context, the need for drinking water is still immense, as well as for electricity supply. Multipurpose SHP provides a solution to both needs.[6]

Between returning from Madagascar and starting this research, the author worked for the engineering and consulting firm STUCKY Ltd, a leading Swiss firm in hydropower. He was involved in several feasibility studies for SHP projects where the technical solution and financial support was known, but, for institutional reasons, the projects would still not take off. This confirmed the wish to return to academia to research into possible solutions to the problem. Whilst working at STUCKY Ltd the author worked on two large hydropower projects (KWO+[7] and Linthal 2015[8]), the latter being a pumped-storage project which triggered ideas for small scale applications.

The main motivation to return to academia and a PhD, from the private sector, was to devote more time to scientific and conceptual research regarding the interface between engineering, economics and institutional matters in network industries and using a specific example, i.e. SHP. Network industries are complex industries providing essential services and currently undergoing major institutional changes due to the liberalisation process which affect the technologies. Research on network industries has thus to be multi-disciplinary.

The overall goal for this PhD research is to increase the amount of renewable electricity produced by SHP in Switzerland and, hopefully, worldwide. The deployment of SHP will increase by using the remaining technical and ecological potential under economically viable conditions.

1.3 Research objective, results and contribution to the literature

The **objective** of this research is to identify the institutional framework that favours the facilitation of SHP in Switzerland. The thesis is mainly written for public and private sector decision makers – for the former to contribute to policy-making and to the shaping of the institutional framework and for the latter to develop private sector initiatives.

The main **results** are identified policy instruments and conditions which facilitate SHP in Switzerland (see Chapter 6), which are either new developments or improvements on existing instruments and conditions. Instruments are also identified for the particular focus of the research on storage and pumped-storage SHP (see Section 8.2). Recommendations for a more coherent overall institutional framework related to SHP in Switzerland are suggested, contributing to further align technology and institutions. These improve the facilitation of SHP, and therefore lead to more renewable electricity production. The policy instruments can be adapted to the specific context and, hopefully, adopted by other countries in Europe as well as worldwide.

A **specific result** of the research is the explorative evaluation of the storage and pumped-storage SHP potential in Switzerland (see Chapter 7 and Section 8.1). To this end, an assessment methodology is developed which is readily applicable in future analysis. As the evaluated technical potential is important, the institutional framework allowing an economic deployment is analysed within the above described research. This leads to recommendations for policy-making and the identification of concrete projects for further development.

The research used the so-called "coherence framework". A **contribution** of this research is to further substantiate this framework (currently qualitative and conceptual) with a concrete illustration, i.e. SHP. The SHP case is an innovative case as only a few concrete illustrations have so far been presented using the coherence framework. In addition, the author contributes towards further development of the framework regarding the importance of

[6] One paper was written on SHP in developing countries at the beginning of the PhD (Crettenand and Hemund, 2010).
[7] http://www.grimselstrom.ch/kwoplus (accessed on 08.12.2011)
[8] http://www.axpo.ch/axpo/en/hydroenergie/wissen/kraftwerksprojekte/ausbauprojekte_linth-limmern.html (accessed on 08.12.2011)

performance in network industries. The concept of alignment between institutions and technologies in the case of network industries is refined. The improved coherence framework can be applied to other network industries.

The analysis and policy recommendations contribute to the literature and research of MHP, SHP and distributed and renewable electricity generation.

1.4 Structure of the thesis

Figure 1-1 illustrates the research design which lays out the structure of the thesis. The first part of the thesis (Chapters 1 to 5) defines the research question and objective, as well as the context. The theoretical framework is described. Based on the framework, the SHP technology and its institutional framework in Switzerland were studied during the research.

The second part of the thesis (Chapter 6) analyses the institutional framework for SHP in Switzerland based on the previous Chapters. During research for this, the opportunity of storage and pumped-storage SHP was identified. This leads to the third part of the thesis (Chapters 7 and 8), for which the research was conducted in parallel to the second part and which developed and analysed the potential of storage and pumped-storage SHP as a RET for flexible electricity production and energy storage.

The conclusion (Chapter 9) derives from both analysis in Chapters 6 and 8, as well as from the contribution to the development of the theoretical framework.

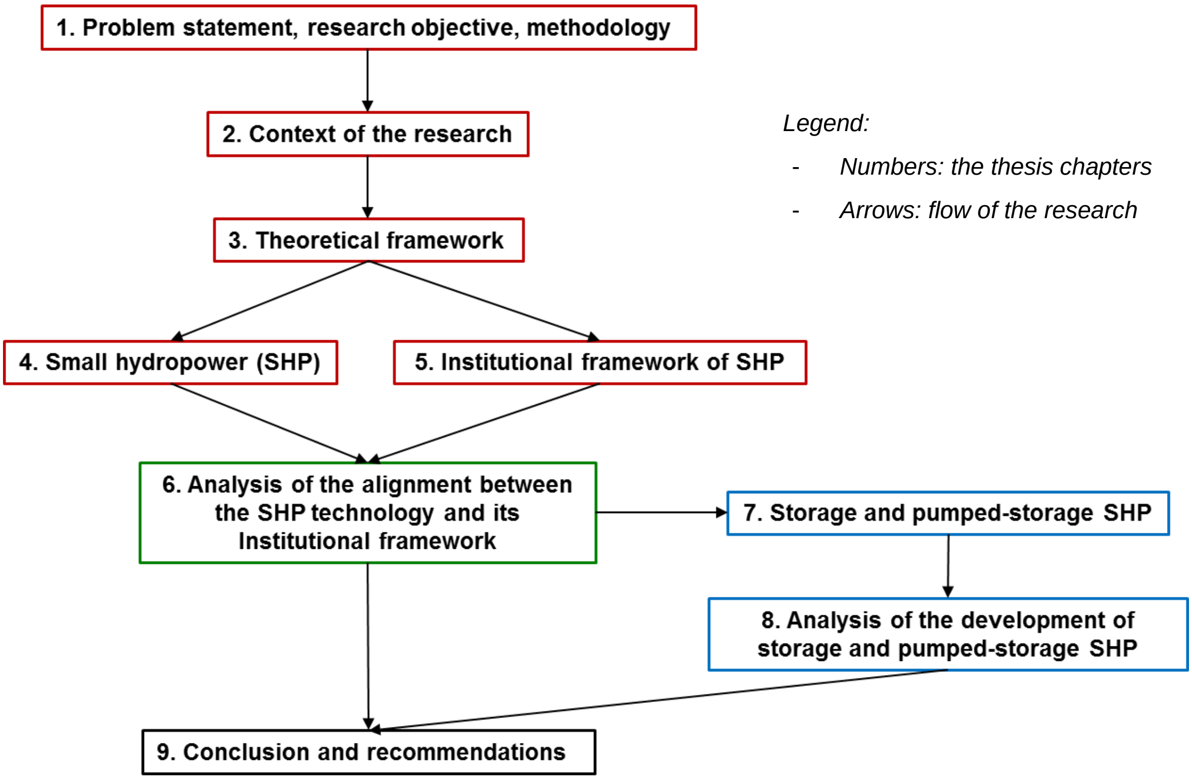


Figure 1-1: Research design

Chapter 1 of the thesis outlines the problem statement, the research results and the contribution to the literature, as well as the structure and methodology of the research. A first version of the problem statement had been established before the beginning of the thesis thanks to work experience on SHP prior to the PhD. The main research question was thus formulated in the early stage of the research. The research sub-questions emerged during the second part of the research and reshaped the problem statement, as well as the expected results. The methodology was also subsequently adjusted to include the research on storage and pumped-storage SHP (see Section 1.6).

Small hydropower being a technology to produce electricity, the context of the research is provided by the electricity sector in Switzerland as described in Chapter 2. As a network industry, the electricity sector is undergoing major institutional changes following the liberalisation process. On the technological side, the importance of RETs for electricity production is increasing.

Chapter 3 develops the theoretical framework for the research, namely the coherence framework. The framework is based on the literature on co-evolution between institutions and technologies in the case of network industries. This literature and this framework have been chosen because they include both institutions and technologies, as well as their interaction, into the analysis of network industries. Furthermore, they have never been used to analyse SHP. An approach based on the coherence framework is relevant, as SHP is part of a network industry.

Based on the two components of the coherence framework, institutions and technology, SHP is introduced first from the technological perspective in Chapter 4. The technology is described, including the latest innovation developments. The SHP history and potential in Switzerland are discussed, as well as some more details for the Canton of Valais. This Canton was chosen as the geographical unit for some of the analysis (see Section 1.5). Finally, the role of SHP in Europe and worldwide is briefly introduced.

Chapter 5 develops SHP from its institutional perspective. It introduces the stakeholders and describes the institutional framework of SHP in Switzerland, including legislation and policy instruments. Some institutional aspects of the Canton of Valais are also introduced. Like in the previous Chapter describing the technology, a brief look at the neighbouring countries follows in presenting their policy instruments related to SHP.

In Chapter 6, the institutional framework for SHP in Switzerland with regards to the alignment between institutions and technology is analysed. The analysis mainly concerns policy instruments which can either facilitate the development of SHP and/or ensure a better coherence between the technology and its institutions. This Chapter addresses the main research question and develops part of the main research results, i.e. policy instruments.

During the research, storage and pumped-storage SHP was identified as an example of co-evolution between institutions and technologies. The argument to develop storage and pumped-storage schemes below 10 MW is elaborated in Chapter 7. In order to evaluate the potential of such schemes, an assessment methodology was developed. The methodology was applied to the Canton of Valais.

Chapter 8 analyses and discusses the results from the potential evaluation of storage and pumped-storage SHP. The Chapter answers the two research sub-questions and presents the other main results, i.e. the policy instruments, as well as the specific results (i.e. potential of storage and pumped-storage SHP in Switzerland).

Finally, Chapter 9 concludes on the research. It discusses to which extent the research objective has been achieved, as well as the research limitations. It highlights the key results leading to policy recommendations and the contribution of the research towards development of the theoretical framework. Future research possibilities are outlined.

1.5 Unit of analysis

Switzerland is the selected unit of analysis; for the particular focus on storage and pumped-storage SHP the study is restricted to the Canton of Valais. Switzerland was selected due to its unique institutional framework (e.g., Federalisms, strong multi-level governance, non-EU member), and its significant hydropower potential (see Section 2.2.2). In addition, the research was co-funded by a Swiss corporation, EOS Holding.

The research on SHP takes into account the whole country because SHP plants are developed across the entire territory shown by the Figure 1-2. This Figure shows the SHP plants receiving the feed-in remuneration in 2010 and is an accurate representation of on-going development and further potential of SHP in Switzerland. A consolidated database and map of all operating SHP plants does not exist even though the project to set up such a database was launched a few years ago (see Section 4.2.1). The plants above 300 kW are inventoried in the Federal yearly statistic[9].

Source: (Manser, 2011: 36)

Figure 1-2: SHP plants receiving the feed-in remuneration in 2010

The time frame of the analysis is from 2009 (introduction of the feed-in remunerations as major institutional change – see Section 5.2.2) to the beginning of 2012 (end of the research). The results and recommendations of the research are addressed to policy making within the Energy Strategy 2050 of the Federal government, the post-Kyoto framework (2013-2020), the second phase of the liberalisation of the electricity sector (post 2014) and the revision of the Federal Energy Law (on-going during the research[10]).

For the evaluation of the storage and pumped-storage SHP potential, as well as for the more detailed analysis of some institutional aspects, the research studied one particular Canton. Cantons are the relevant sub unit for more in-depth analysis, as certain policy instruments, such as water rights and administrative procedures, are specific for each Canton (see Section 5.2).

The Canton of Valais was chosen because it is one of the Cantons with the highest remaining potential for SHP deployment according to feed-in remunerations projects demands[11] and on-going evaluations[12]. It is, as well, the Canton with the highest hydropower production in Switzerland and with the highest production from SHP plants

[9] http://www.bfe.admin.ch/themen/00490/00491/index.html?lang=de&dossier_id=01049 (accessed on 15.08.2011)

[10] The author participated at the consultation of the revision of the Federal Energy Ordinance in spring 2011.

[11] http://www.stiftung-kev.ch/berichte/anmeldestatistiken.html (accessed on 15.08.2011)

[12] Within the on-going evaluation of the Swiss hydropower potential by the SFOE, the Canton of Valais has the highest forecasted additional SHP production, along with the Canton of Bern (Presentation of the results of the survey "Wasserkraftpotenzial der Schweiz", SFOE, Ittigen, 14.02.2012).

receiving the FIR (see Table 1-1). The Canton of Valais also has an important potential for multipurpose infrastructures for which the Blueark Program had recent data available (see Section 4.2.3). In addition to the technical potential of hydropower, there is also a political will in the Canton of Valais to increase the hydropower production with additional measures and to develop additional storage and pumped-storage schemes (Cina, Balet et al., 2011). Furthermore, the Canton is a location of work for the co-funding partners.

Table 1-1: The 3 Cantons with the highest hydropower production in Switzerland

Canton	Hydropower - operating plants[1]			SHP plants receiving the FIR (in operation or with positive notification)[2]		
	Installed capacity [MW]	Expected production for 2011 [GWh]	% of Swiss hydropower production	Installed capacity [MW]	Production 2010 [GWh]	% of FIR SHP production
Valais	4'642	9'594	27%	89	326	22%
Graubünden	2'648	7'868	22%	38	163	11%
Bern	1'317	3'293	9%	72	315	21%

Sources: [1] (BFE, 2011g, Tab. 12)

[2] http://www.stiftung-kev.ch/berichte/anmeldestatistiken.html (accessed 15.08.2011): Statistics for 2010

Remark: The 3 Cantons generate 58% of the hydropower production and 54% of the SHP production with plants receiving the FIR.

1.6 Methodology of the research

The research was elaborated on a qualitative and explorative basis, and applied the coherence framework to the specific case of SHP in Switzerland. The research was multidisciplinary and included engineering, economics and institutional theory in order to build on the literature on co-evolution between institutions and technologies in the case of network industries.

The purpose of the thesis is applied research, thus contributing to the development of useful theories and knowledge to help interested parties to better understand the nature of a problem so that they can solve it or, at least, control more effectively their environment (Patton, 2002: 153 + 160). Ideas and concepts are developed and refined during the research. The data collection and analysis is an iterative process. The researchers themselves are an important part of the research process, *"either in terms of their own personal presence as researchers, or in terms of their experiences in the field and with the reflexivity they bring to the role – as are members of the field under study"* (Gibbs, 2007: XI).

The methodology is qualitative. It investigates a phenomenon (i.e., SHP) within its real life context. Qualitative research can deal with many (uncontrollable) variables in this context. Multiple data sources are taken into account and comparative analysis leads to common patterns and offers the possibility of generalisation. However, obtaining causalities can be difficult and the risk of selection bias remains. A traditional mixed methods approach (i.e. "concurrent triangulation strategy") is used to remedy this problem. Different methods have been used to obtain data, including literature reviews, interviews, a survey, and participant observations and discussions and meetings with specific stakeholders (e.g., Federal parliament, Federal administration, electricity producers, SHP umbrella organisation, TSO, research laboratories, engineer offices, Cantonal administration)[13]. The multiple

[13] Data obtained through participative research is mentioned as footnote in the thesis.

sources of evidence led to the development of converging lines of the inquiry. There was not only a methodological triangulation, but a data triangulation as well. The data of the interviews and participant observations were combined with the survey data. This approach enabled corroboration of findings through the comparison of results, which made the research more robust. Emphasis was placed on methodical data collection - gathering the same information from various sources so that it is replicable. The chain of evidence was maintained through the whole research and the structure of the thesis reflects the chain (e.g., intermediary results of Chapter 6 leading to the research in Chapter 7 and 8).

Most of the collected data was qualitative and concerned the institutional framework and policy instruments. Some data coming from the survey was quantitative and gave information on some of the policy instruments, as well as on the potential evaluation of storage and pumped-storage SHP. This evaluation combined both qualitative and quantitative data (see Section 8.1).

The validity and reliability criteria of the research are ensured thanks to the methodological triangulation and the multiple sources. The data is up to date and gathered from the key stakeholders in the field of research. The feedbacks on the empirical results contributed to validate the obtained results.

Before this research started, SHP had been chosen as a topic because of the interest and previous work experience of the author. The author knew about the technology and the need for further evolving institutions and that this evolution would have to occur within the dynamics of the electricity sector.

Literature reviews were conducted for most of the Chapters of the thesis, and were completed in much more depth for Chapters 3, 4 and 5. For Chapter 3, the whole literature on the coherence framework was reviewed in order to include the latest developments of the framework into the research, as well as the initial concepts. After the literature review, the author contributed towards the development of the framework in order to fill some gaps in the literature and participated to this end by attending various conferences and workshops[14]. The framework shaped the whole research.

For Chapters 4 and 5, the relevant literature concerning SHP in Switzerland was reviewed. On the one hand, the review concerned the technology (including history and potential), and, on the other hand, it concerned the institutions related to SHP (e.g. legislation and policy instruments).

The literature reviews laid the ground for the research with the interviews, the survey and participant observations. For example, before starting with the interviews, a list with the existing policy instruments in Switzerland was established. The interviews led to further development of this list. Another example was the technological innovation whereby the interviews refined and updated the data from the literature. Finally, the study of the SHP technology and its institutional framework contributed towards formulating the questions for the survey.

The limitations of the literature reviews mainly concerned Chapter 5, where only literature relevant for the research of SHP in Switzerland was considered and not an overall study of all policy instruments used worldwide in theory and in practice.

Based on the data obtained regarding the SHP technology and its institutional framework and based on the coherence framework, the analysis evaluated the alignment between the SHP technology and its institutions in Switzerland. To this end, additional data was gathered from interviews, the survey and participant observations. The interviews allowed discussions on new policy instruments, as well as adapted ones. Furthermore, specific

[14] E.g. (Crettenand, Laperrouza et al., 2010; Crettenand, 2011a) and Workshop on Performance in Network Industries, EPFL and Florence School of Regulation, 6-7 October 2011, Florence, Italy. (http://mir.epfl.ch/files/content/sites/mir/files/users/181931/public/cfp_performance.pdf (accessed on 07.12.2011))

problems concerning the facilitation of SHP were identified in order to be discussed later in the research. The sampling for the interviews was based on interviewing representatives of all main stakeholders within the research topic (see Section 5.1 for the stakeholder analysis). 19 interviews with key stakeholders have been conducted (see Table 1-2 for the interviewee list). Chain sampling was used to identify further interviewees.

The interviews were done with an active interviewer approach. Active interviewing is not restricted to asking questions and recording the answers. It is an interactional process during which the interviewer keeps the conversation going. The interviews were semi-structured interviews which allowed quick retrieval of the relevant data and led to a pertinent capitalisation of the key questions and problems within the research topic. The structured part of the interviews allowed a certain standardisation of the data, whereas the open part allowed the interviewee to raise up his/her key concerns within the research topic. Interviewing more than one person enabled the author to reduce the Hawthorne effect[15] and to validate information by several different sources. The more standardised the interview, the easier is the capitalisation afterwards, but, on the other hand, the meaning-making linkages are less obvious and visible. Therefore such linkages are obtained through the open part of the interview.

A first round of interviews was conducted at the Federal level providing data mainly on the SHP technology (Chapter 4), the institutional framework (Chapter 5) and the analysis of the institutional facilitation of SHP (Chapter 6) (11 interviews). The most promising instruments were identified and compared with the instruments in place in neighbouring countries. The instruments were then further developed during the research. A second round of interviews followed mainly at the Cantonal level for refining the analysis and evaluating the potential of storage and pumped-storage SHP (Sections 6.1 and 6.2 and Chapter 8) (8 interviews). The second round also included some interviews at the Federal level.

The list of the questions for the interviews at the Federal level can be found in the Appendix A and for the Cantonal level in Appendix B. The interview questions were asked in French or German, and slightly adapted depending on the interviewee in order to focus on his domain of expertise.

[15] "*The Hawthorne effect is a form of reactivity whereby subjects improve or modify an aspect of their behaviour being experimentally measured simply in response to the fact that they know they are being studied, not in response to any particular experimental manipulation.*" http://en.wikipedia.org/wiki/Hawthorne_effect (accessed on 08.12.2011)

Table 1-2: List of the interviewed stakeholders (in alphabetic order)

Round	Level	Name	**Organisation** (see also Section 5.1)
2	**VS**	Bernard, Marc	Environmental protection office of the Canton of Valais
1	**CH**	Casanova, Michael	ProNatura
1	**CH**	Chenal, Raymond	ADUR (SHP umbrella organisation)
2	**VS**	Crettenand, Narcisse	Cantonal parliament
2	**VS**	Délèze, Philippe	SEIC-Télédis (local electricity distributor)
1	**CH**	Denis, Vincent	MHyLab (SHP research laboratory)
2	**VS**	Galé, Pierre-André	Gasa SA (turbine manufacturing)
1	**CH**	Guggisberg, Bruno	Swiss Federal Office for Energy (SFOE)
2	**CH**	Jorde, Klaus	Hydropower research program of the SFOE & Entec (engineer office)
2	**VS**	Michellod, Paul	FMV (electric utility)
1	**CH**	Nussbaumer, Eric	Federal parliament
1	**CH**	Parmelin, Guy	Federal parliament
2	**VS**	Perruchoud, Dominique	The Ark (promotion of SHP in Valais (Blueark))
1	**CH**	Rouiller, Jean-Marie	ADUR (SHP umbrella organisation) and SIL (electricity utility
1	**CH**	Rüetschi, Matthias	SwissEnergy for infrastructures (SFOE)
1	**CH**	Savoldelli, Luca	Groupe E / Greenwatt (electric utility)
2	**VS**	Storelli, Stéphane	SI Bagnes (small electric utility)
2	**VS**	Truffer, Amadée	Energy office of the Canton of Valais
2	**CH**	Vollenweider, Stefan	Water agenda 21 (NGO)

Legend: 1st column indicates in which round the interview took place and the 2nd column at which level (Switzerland = CH, Valais = VS)

The limits of the interview method are the number of interviews and the fact that the author increased his knowledge with each interview which allowed for the evolution of the discussion during the open questions as the research continued. Therefore, it can be considered that the open part of the interview was not standardised across the sampling.

Within the research of a master thesis at the ETH Zürich on the feed-in remunerations for SHP in Switzerland (Manser, 2011), a survey was sent to all operators of SHP plants who benefited from the feed-in remuneration in 2010. The survey was officially sent by the Swiss Federal Office for Energy (SFOE) combined with the yearly questionnaire that operators must complete. The sample was 190 questionnaires. Some questions were added to the questionnaire by the author of this research. The questions were based on the previous research, mainly the interviews, and they concerned the data collection for the evaluation of the storage and pumped-storage SHP potential in Switzerland (Chapter 8), as well as some questions on the policy instruments (Chapter 6). The answers to the questions were used to complete and validate the data obtained by the other research methods (e.g., interviews and participant observations).

The survey is a method to reach many stakeholders within the research field. With limited time, stakeholders can give their answers to the standardised questions. The open questions provide the opportunity for each stakeholder to personalise their view. The researcher aims to generalise the results based on the sample of the returned survey documents in order to discover underlying patterns.

In the part of the survey related to this research, some questions were quantitative (e.g., introduction of a SHP quality label – yes/no, potential of storage schemes, etc.), other were open and qualitative (e.g., any option to further facilitate SHP). The survey is given in the Appendix C and the corresponding questions are 6 and 7.

The limits of this survey were that it did not reach all SHP plant operators in Switzerland, but only those benefiting from the feed-in remunerations. However, by adding his question to the survey for the research on the feed-in remuneration scheme, the author had an opportunity to get additional data without having to design his own survey.

An unexpected outcome was the sampling configuration, as only 44 answers (23%) were from plants with an installed capacity above 300 kW. Therefore, more than three-quarters of the answers came from MHP plant operators, even micro plants (~50% below 50 kW). This caused bias of the results, which is discussed in Section 8.1.1.

Participant observations also provided some data. The author attended several Swiss events related to SHP (e.g., meetings organised by the WasserAgenda 21[16], SFOE workshop on the hydropower potential in Switzerland[17]) and international conferences where SHP was the main topic or one of the topics discussed (e.g., Hidroenergia 2010[18], HYDRO 2009 and 2011[19]). He took the role of participant observer in contributing to the discussions whilst observing them.

Participant observations as participatory research can bias the data collection and analysis because the researcher is too involved himself within the research field. For example in the case of the potential of storage and pumped-storage SHP, the author's development of policy instruments was well received in many discussions and presentations, but when presented to another Section within the SFOE, not responsible for SHP, the instruments were criticised. This underlines the importance of several data sources beyond the main research field on SHP. The potential bias of participant observation was therefore addressed by the data and methodological triangulation (see above).

Participant research, however, offers opportunities to influence the research topic during the research. The author, for example, participated in the consultation for the revision of the Energy Ordinance (see Table 5-2) and communicated with a member of the Federal parliament concerning his motion regarding the streamlining of administrative procedures for RETs[20].

The data collection and analysis was iterative between the interview rounds, the survey and the participation at events and conferences. Intermediary results were presented at conferences (Crettenand, 2009, 2010;

[16] http://www.wa21.ch/index.php (accessed on 15.08.2011)
[17] Workshop "Energiestrategie 2050: Wasserkraftpotenzial der Schweiz", Bern, 15.11.2011.
[18] http://2010.hidroenergia.eu/ (accessed on 15.08.2011)
[19] http://www.hydropower-dams.com/ (accessed on 15.08.2011)
[20] Personal communication with Sep Cathomas, member of the National Council, during 2010 and 2011.

Crettenand and Finger, 2010; Crettenand and Denis, 2011) and to the EOS Holding[21] committee co-funding this research. The committee provided constructive feedback on a bi-annual base.

With the analysis of the institutional framework for SHP in Switzerland and taking into account the dynamics in the electricity sector, the two sub-questions mentioned in Section 1.1 were added to the research to explore the potential of storage and pumped-storage SHP. The specific context for flexible electricity production and energy storage was reviewed. The assessment methodology elaborated to evaluate quantitatively the potential of storage and pumped-storage SHP was a bottom up development. It analysed some project examples within the Canton of Valais in more depth with a simple Excel-tool developed by the author. The tool enables a brief technical-economic analysis of a project. The institutional feasibility of storage and pumped-storage SHP was discussed in the interviews, with the committee of EOS Holding and at conferences where the author presented[22].

In order to improve and validate the results obtained in the analysis, not only the intermediary results were presented (see above), but also the final results (i.e., policy instruments and potential evaluation of storage and pumped-storage SHP, see Section 1.3). The final results of the research were presented at one of the two main worldwide hydropower conferences (Crettenand, 2011b) and at the multi-disciplinary conference on network industries which includes participants working with the same theoretical framework (Crettenand, 2011a). Both conferences helped finalise the conclusions of the research. In addition, the final results were presented to the EOS Holding committee[23] and at two meetings with the SFOE[24].

Conclusion

This Chapter outlined the research completed to fulfil the research objective of identifying the institutional framework that would further facilitate SHP in Switzerland. The motivation came from previous work experience and the interest in network industries such as electricity. The research was qualitative and considered the SHP technology and its institutions, as well as their co-evolution. The framework of coherence between institutions and technologies in the case of network industries was used as theoretical framework and shaped the research. The research led to identification and further development of policy instruments and conditions which facilitate SHP in Switzerland.

[21] http://www.eosholding.ch/ (accessed on 15.08.2011)
[22] (Crettenand, 2011b; Crettenand, 2011a; Crettenand and Denis, 2011)
[23] Comité de Suivie des projets EOS Holding, 10.11.2011, Lausanne, Switzerland
[24] Meeting with Bernhard Hohl, 11.10.2011, Ittigen, Switzerland, and meeting with Thomas Volken, Stefan Dörig und Sebastian Dickenmann, 05.12.2011, Ittigen, Switzerland

2. Context of the research

Small hydropower (SHP) is a renewable energy technology and as such part of the electricity sector. The electricity sector is a part of the network industries. These industries are currently undergoing liberalisation which is a major institutional change. This change affects the operation of the electricity sector and is therefore relevant for this research on SHP. The facilitation of renewable energy technologies (RETs), including SHP, is another institutional change relevant for this research.

This research focuses on the production of electricity, rather than on the management of a water resource. SHP produces electricity; it does not supply water. Therefore, the electricity sector is reviewed in this research and not the water sector. Some aspects related to the water sector are mentioned in later Sections (e.g., water concession regulation, regional approach to water management including SHP), as they concern electricity production.

This Chapter describes the context of the research starting with the broad perspective of network industries and then concentrating on the electricity sector in Switzerland, more specifically on the RETs (see Figure 2-1). Following the differentiation between institutions and technologies in the theoretical literature and framework of Chapter 3, both institutional and technological aspects of network industries and the electricity sector are considered. This Chapter develops an overview of network industries and in particular for the electricity sector and Section 3.2 describes the dynamics and the co-evolution between the institutions and technologies in the case of network industries.

SHP is not part of the context and is therefore introduced in Chapter 4 (SHP technology) and Chapter 5 (institutional framework and stakeholders related to SHP).

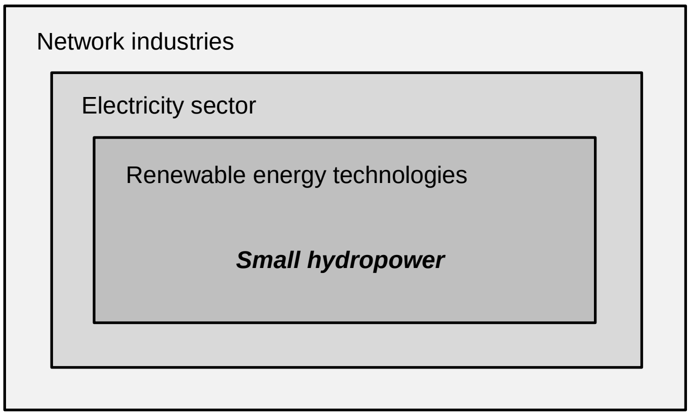


Figure 2-1: Context of the research

2.1 Network industries and the liberalisation

Network industries, such as electricity, railways, air transport, drinking and waste water, gas, and telecom provide essential services. They are very complex technical, economic and political systems. They are based on physical networks and have high asset specificities. Technical or institutional failures within the network have significant and large scale systemic consequences. Network industries exhibit interdependencies and support other technologies. Their macroeconomic role tends to be underestimated. In Switzerland, network industries contribute to 5.3% of the GDP and to 4.5% of the employment (Bundesrat, 2010). They are a necessary prerequisite for economic prosperity and social welfare. The expansion of network industries is determined by population and economic growth, but limited by resources such as space, finance and raw materials.

Various definitions for network industries exist and referrals are made to them using words such as infrastructures, critical technical systems, large technical systems, socio-technical systems, and public utilities. Three definitions below are taken from the literature.

The first definition comes from Finger et al., which is the main reference paper for Chapter 3. Network industries *“have to be coordinated over a large geographic area, involving different technologies and standards, as well as numerous economic and political actors with diverse objectives and interests. Technical conduct of single elements and individual economic behaviour is not arbitrary but needs to be synchronized in order to safeguard the proper functioning of the network and hence deliver the desired performance. Failures in technical, economic or political coordination might have significant repercussions because modern societies depend very much on infrastructures’ essential services”* (Finger, Groenewegen et al., 2005: 228). The essentiality relates to the role of network industries for economic development and social well-being (IRGC, 2006).

Glachant describes the features of network industries as follows: *“substantial economies of scale or scope (extending to natural monopolies); far-reaching externalities (positive or negative) in production or consumption; and extensive vertical and horizontal integration (either under a single corporate umbrella or in the form of ad hoc contracts)”* (Glachant, 2002: 297). To this list, it can be added that the products/services of network industries are massively consumed (Spiller and Tommasi, 2005: 518).

The third definition from Weijnen and Bouwmans describes network industries as systems *“designed to satisfy specific social needs, but they shape social change at a much broader and more complex level. Electric power supply has radically changed our households, and telecommunication services and the internet have changed mobility patterns. Like the railway and airway transport infrastructures, telecom and information infrastructures have greatly accelerated the internationalisation of companies and markets. They have also created the platform on which new infrastructures for financial transactions, health care and education could emerge. Infrastructures are so deeply embedded in all economic and social activity that they are often taken for granted, and they are used without specific reflection. When everything runs smoothly, we are unaware of the complexity of infrastructures and infrastructure-related vulnerability. We only realise this vulnerability when faced with service interruptions. A number of large scale power blackouts (London, Italy, California, New York) and successful virus attacks on the internet have brought to light how critical the role is that infrastructures play in our economies.”* (Weijnen and Bouwmans, 2006)

Several key issues need to be highlighted at this point. Firstly, network industries are conceived as complex systems in which technological and institutional elements are strongly interwoven (Hughes, 1987). There is a co-dependence and co-evolution between the institutions and the technologies, whereby institutions are defined according to North (1990) in this research (see Chapter 3). This co-evolution is further elaborated in Chapter 3.2.

Secondly, the specificity of networks matters. Network industries are networks both from the technological and institutional perspective. They vary across the sectors, but the network features of positive consumption externalities (or network externalities) applies to the technological perspective and signifies the fact that the value of a unit of the good increases with the number of units sold (Economides, 1996). Therefore, the more nodes that are linked together, the more the value of the network increases. The technological side of network industries is determined by networks that are connected through various nodes and links. As a consequence, complementarities within the system requires the coordination of activities (Künneke and Finger, 2009). E.g., in electricity, the delivery depends among others on the coordination between production units in order to cover the demand in real time. Such complementarities create strong mutual interrelations between the technological and institutional side of network industries, as well as among the actors.

Thirdly, network industries show a tendency towards an increasing size and complexity throughout history (Künneke and Finger, 2009). Many infrastructures started as local initiatives, but evolved into regional, national and international networks. They started as a local public monopoly. The fully vertical integration was justified by the monopoly character of the network (e.g., for a city, a region or a country). In the meantime, much has changed. For example, electricity reached a scale and degree of complexity that is hardly to be monitored by a single, local and central point anymore. The technological scope generally crosses national borders and thus creates the need for international coordination. The technological side, such as in electricity, remains almost the same across the borders, however the institutional side varies much more.

Fourthly, across the various network industries a certain convergence among the sectors can be observed. For example the electricity and gas sector converge with the significant implementation of combined heat-power plants, especially for distributed generation. Network industries are thus not only more and more interconnected across borders, but also across sectors (Weijnen and Bouwmans, 2006). Most network industries depend not only on ICT, but on energy services as well (IRGC, 2007). Within the electricity sector, some of the production relies on gas supplies, some on the rail network for the transportation of coal and there is increasing dependency on ICT systems. Within this convergence of sectors, failures can cascade from one infrastructure to the next which has to be prevented. Four basic types of convergence can be distinguished (Bauer, Weijnen et al., 2006):

- physical convergence (multi-functional infrastructures),
- organisational convergence (multi-utility companies),
- market convergence (in substitutes or in complements),
- spatial convergence (clustering in corridors).

Fifthly, network industries are conditioned by asset specificity and a high level of sunk costs. The owners are therefore stuck with their infrastructure and need to be able to recover their investment costs during the operational time.

Finally, there are some arguments and evidences that network industries are increasingly vulnerable to systemic failures (Laperrouza, 2009). Network industries are subject to rapid changes that can pose risks and have cascading effects within the industry or across network industries (IRGC, 2006). Such systemic risks have not been the topic of extended analysis (Laperrouza, 2009). Various network industries face different risks linked to several criticalities measured along their scope (i.e., the geographical extent of the effect of a failure), their magnitude (i.e., the size of the effect in the afflicted area) and the time effect (i.e., the speed with which a failure has an effect) (IRGC, 2007). Overall, failures within network industries entail massive costs for society. Accurate cost figures are difficult to obtain and cost estimates on the same incident often diverge largely, depending on cost definitions and strategic interests. Nevertheless, some cost figures may show the order of magnitude (Weijnen and Bouwmans, 2006): the costs of the major power failure in the USA and Canada on 14th August 2003, which affected 50 million people, were estimated at around 6 billion US$; the costs of the Italian power failure on 28th September 2003, which affected some 57 million people, can be assumed to be of the same order of magnitude (the blackouts lasted between a few hours to more than a day). Granted that there are many uncertainties in these figures, it can be concluded in all industrialised countries that even the more conservative estimates of the direct costs of interruptions in services are substantial. Industrialised country economies are increasingly relying on ICT requiring electricity, the dependence to this energy vector is very strong.

2.1.1 Liberalisation in network industries

The network industries have undergone significant reforms over the past 30 years, i.e., de- and re-regulation within the liberalisation process. The liberalisation process refers to the introduction of competition in situations or sectors so far characterised by monopolies (including unbundling[25] which is a pre-requisite for introducing competition, privatisation[26], public-private-partnerships, third-party access, and other measures related to market structures). Its economic rationale is grounded on the recognition, that in principle, competition is more prone to achieve efficiency than monopoly (Luis-Manso and Felisberto, 2006). Newberry shows that competition is more important than ownership (e.g., public, private, public-private-partnerships) towards reaching the goals of the liberalisation processes (1999: 106).

Liberalisation as a major institutional change appeared as a global phenomenon in countries with different political settings and stages of economic development (Groenewegen, Künneke et al., 2009). In the electricity network industry for example, there have been over 200 sector deregulations between 1990 and 2008 (Glachant and Perez, 2009). Prior to liberalisation, the industries were driven by engineering. They are now increasingly driven by economics (Jonker, 2010). Formerly vertical integrated network industries are becoming fragmented and the different actors, who were previously cooperating, are now competing against each other or at least behaving strategically. The changes within the liberalisation process were mainly institutional with technologies being seen as constant (Finger, Groenewegen et al., 2005).

The original model for the liberalisation was the telecommunication industry, in particular the mobile phone sector. Markets were introduced, regulatory intervention decreased after initially regulating the market openings, and ultimately benefits were generated for the customers (Finger and Varone, 2006). While this original model inspired liberalisation in other network industries, the other industries proved so different that complexity increased and liberalisation took other paths. Therefore, the level of competition now varies across the network industries. Whole networks compete in the case of telecom, post and air transport, whereas competition occurs at the access level in the case of electricity, gas and railways. The water sector is a competition for the local monopoly. (See also Section 3.2.2.)

The aims of reforms differed between network industries. In certain cases, the objective was to increase the economic and systemic efficiency as well as the quality of service by the introduction of competition. In other cases, like in railways, the aim was to reduce the losses incurred by the incumbent state-owned operator. In electricity, according to Joskow, the *"overriding reform goal has been to create new institutional arrangements that provide long-term benefits to society and to ensure that an appropriate share of these benefits are conveyed to consumers through prices that reflect the efficient economic cost of supplying electricity and service quality attributes that reflect consumer valuations"* (Joskow, 2008). Key to the well-functioning of the liberalised electricity market are regulations which ensure competition in the whole sale and retail markets, ensure non-discriminating access to the transmission and distribution network, and incentivise the optimisation of the network (Jamasb and Pollitt, 2008). Overall, the institutional framework has changed from a public utility-oriented system towards a market-oriented system even though electricity is still seen as an essential service.

In most network industries it is not possible to liberalise the complete industry. Some segments remain monopolistic for both technical and economic reasons (e.g., electricity grid, air traffic control, etc.). The unbundling of the industry leads to the vertical separation of competitive segments (e.g., the electricity production and transportation of cargo by rail) from segments that will continue to be regulated. In the competitive segments, a

[25] The process of breaking apart the vertically integrated network industry into separate parts along the value chain (e.g. in electricity the separation of production, transmission and distribution).

[26] Privatisation concerns the change of ownership from public to private.

horizontal restructuring can be necessary to create an adequate number of competing actors to mitigate market power and ensure that markets are reasonably competitive (Joskow, 2008).

Liberalisation leads to re-regulation in order to ensure the fair attribution of scarce resources (e.g., capacity within the network) in the context of competition and unbundling (Finger and Varone, 2006). From an economic regulation perspective, the markets need to be sustained and not simply created. Regulatory incentives deal with the pricing, cross- or direct-subsidies, access, interconnection, etc. (Spiller and Tommasi, 2005). Furthermore, public service objectives have to be enforced (e.g., consumer protection) and technical functions of the network industries (e.g., interoperability, capacity management, etc.) and the security of supply guaranteed. Regulatory policy needs to be stable, coherent, and predictable (Spiller and Tommasi, 2005). It has to remain dynamic to be able to adapt to the changes, also created by the liberalisation process, within the regulated segment of the corresponding sector. Existing actors (e.g., competition authority) or new actors (e.g., sector specific regulator) take over these tasks of regulation, whereby these actors may be in disagreement sometimes. The promised “return to the market” as the sole regulator is still far from being realised (Glachant, 2002). The regulation and the liberalisation of the electricity sector in Switzerland are described in the next Section.

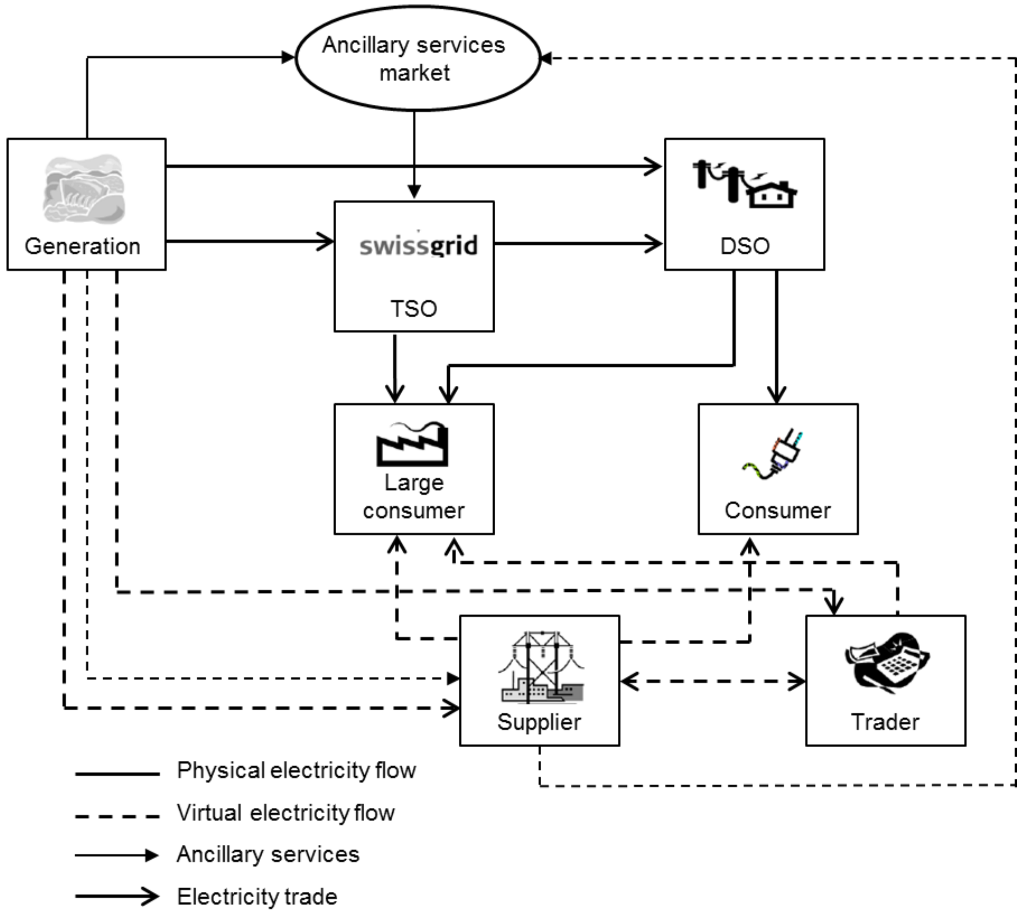
2.2 The electricity sector in Switzerland

Switzerland is an electricity hub within Europe due to its main transit lines and storage hydropower plants allowing peak and flexible electricity production. The policies and perspectives of the country are conditioned by the fact that Switzerland is not member of the EU and will probably not be in the near future. The liberalisation process has its own dynamics and may not always be in line with EU policies.

2.2.1 The electricity market and the liberalisation process

The Swiss liberalised electricity sector is composed of the following segments along the supply chain (see Figure 2-2):

- Generation: Electricity producing companies using nuclear and some fossil energy sources, as well as renewable energy sources. Most of the companies still belong to public entities, such as Communes and Cantons (see Figure 5-1). There are over 800 hundred of them, but the market is getting consolidated. The biggest companies are: Alpiq, Axpo, BKW/FMB, CKW, EGL, EWZ and Repower.
- Transmission: The Transmission System Operator (TSO) – Swissgrid – runs the transmission system in a non-discriminatory way, including the connection of generators, large consumers and underlying distribution networks to the transmission network. The TSO is also responsible for the grid connection of RET plants and the ancillary services. The TSO is regulated by the electricity regulator ElCom. It will become the owner of the transmission network in 2013; it currently belongs to the electricity producing companies.
- Distribution: Distribution System Operators (DSOs) run the distribution system at lower voltage levels that delivers electricity to the end consumers. These remain mainly local/regional utilities. The DSOs are regulated by the ElCom.
- Suppliers and traders: Same or different from the electricity producing companies and DSOs. Suppliers make contracts with final consumers to deliver electricity, regardless of their point of connection. Traders can sell directly to large consumers.



Source: Translated from (Burger, 2011: 16)

Figure 2-2: The Swiss electricity market

The transmission and distribution of electricity is regulated by the Swiss electricity regulator, ElCom[27], which was set up with the market opening. ElCom has the status of an extra-parliamentary commission. The generation, trading and electricity supply are part of the liberalised segments of the sector. In addition to the electricity trade market, there is the ancillary services market operated by the TSO. Ancillary services ensure that the demand and supply of electricity is balanced at any moment in time (see also Section 8.2.1).

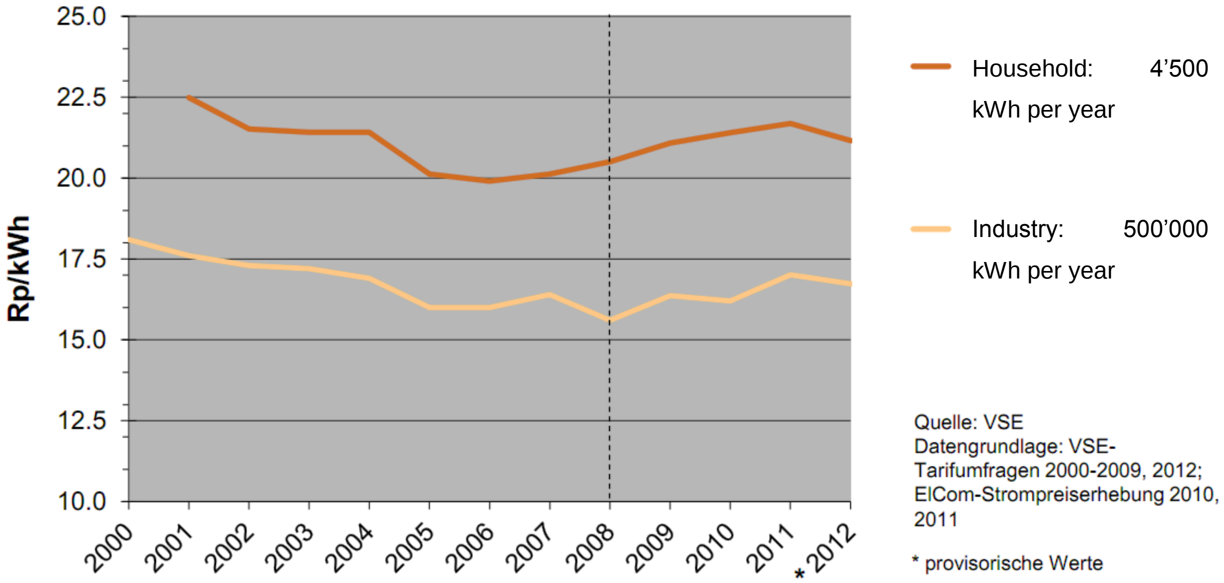
The liberalisation process in Switzerland follows the one in the EU which started in 2000. In the EU, the implementation of the liberalisation takes place in very different ways and remains unsatisfactory in various Member States (Cina, Balet et al., 2011). This is why the EU adopted a third package of measures in March 2009, whose key element is the strict separation between production and transport (i.e. unbundling).

The Federal government aimed to liberalise the Swiss electricity sector in 2003 in line with the EU. However, the Swiss population rejected this by a vote in 2002. The first phase of a regulated liberalisation of the Swiss electricity market began legally[28] on the 1st January 2009 when large consumers (consuming more than 100 MWh/year; about 50'000 consumers accounting for 53% of the market) could begin to freely choose their electricity supplier (Wohlfahrtstätter, 2010). For all other consumers, the market is expected to open in 2014, but

[27] www.elcom.admin.ch (accessed on 27.02.2012)
[28] The legal framework for the liberalised market was passed by the Federal parliament in March 2008 with the Electricity Supply Ordinance and the revised Energy Ordinance.

this is subject to a non-compulsory referendum on the new Law on Electricity Supply[29]. Since 2007, Switzerland and the EU are negotiating an agreement regarding the electricity sector to allow improved integration of Switzerland in the European electricity market (including adaptation to the third liberalisation package of the EU) (see Section 2.2.3).

The liberalisation process did not really change the electricity price in Switzerland[30]. Figure 2-3 shows the price evolution since 2000. Even though the prices rose again after the beginning of the liberalisation process, these increases cannot be allocated solely to the liberalisation. In general, the electricity price in Switzerland remains close to the average in the EU-27 (see Figure 2-4 and Figure 2-5). In Lausanne, the domicile city of the author, the retail electricity price in 2011 was 0.23 CHF and composed of 44% for the network usage, 46% for the generation, 2% for the feed-in remuneration for RET plants (FIR; see Section 5.2.2) and 8% for community taxes[31]. Taking all the taxes into account, 27.9% of the electricity price in Switzerland in 2009 were taxes or other fees, compared to 25.8% in 2007 (Christensen and Wasserer, 2010). The electricity price is likely to rise in the coming years due to the loss of cheap base production (e.g., nuclear plants, see below), the grid expansions and the integration of the RET plants (see Section 2.2.4)

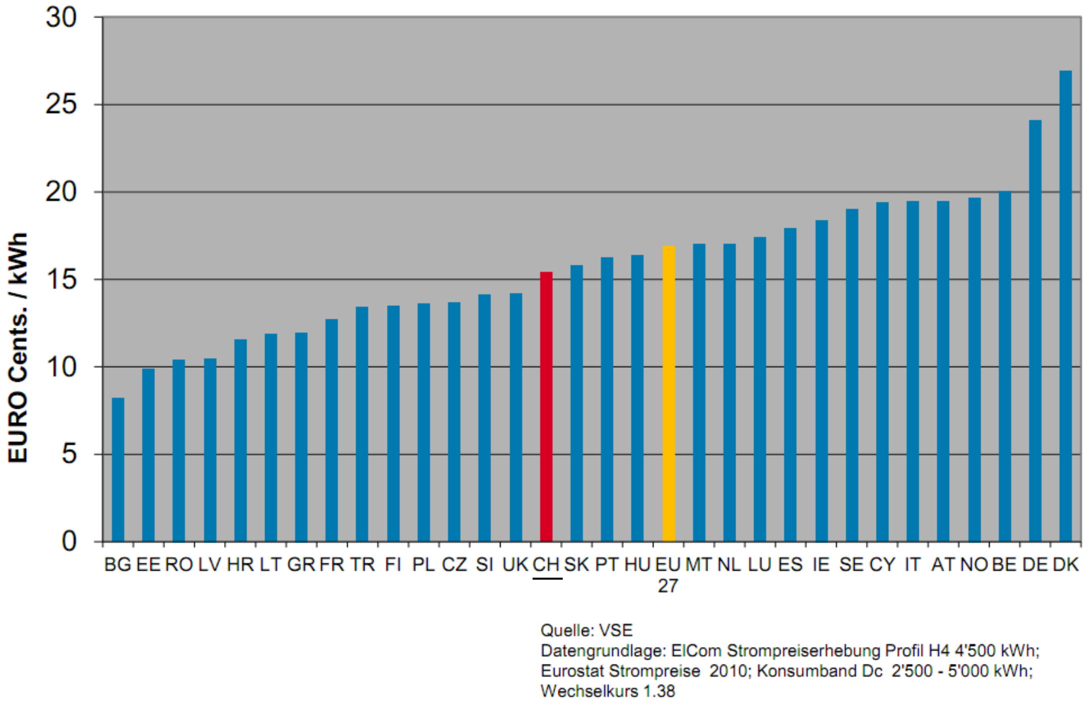


Comments: Household with VAT, industry without VAT. Provisional prices for 2012.

Source: http://www.strom.ch/de/dossiers/stromgrafiken.html (accessed on 30.11.2011)

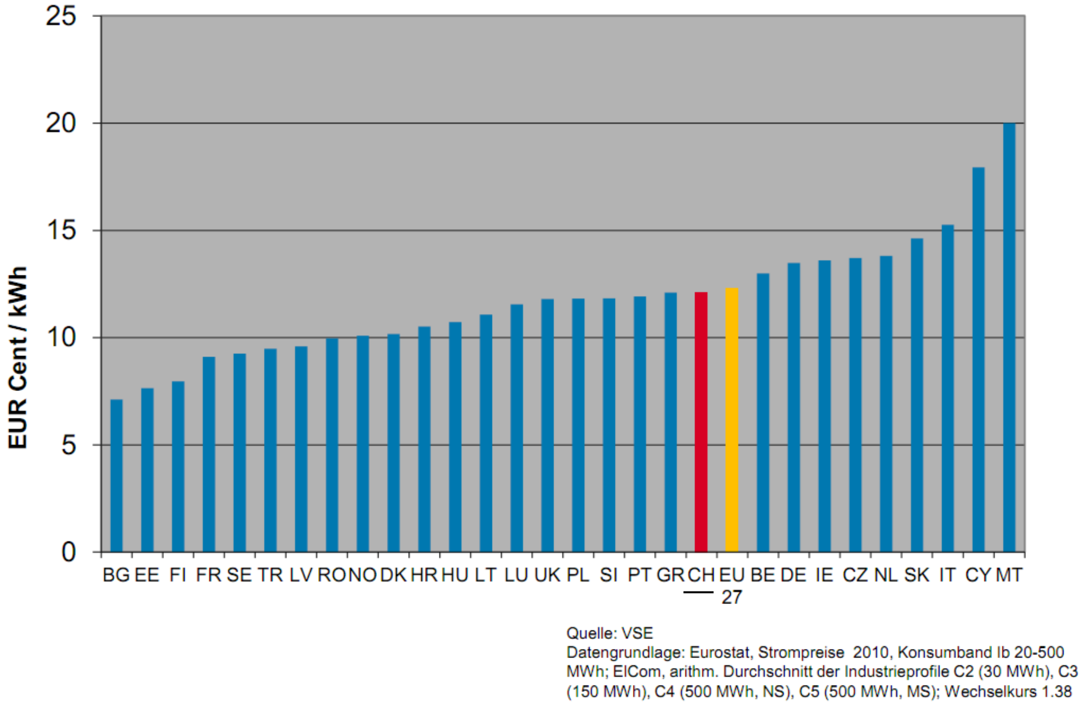
Figure 2-3: Electricity price in Switzerland between 2000-2011

[29] http://www.bfe.admin.ch/themen/00612/00613/index.html?lang=en (accessed on 30.11.2011)
[30] Le Temps, "L'art d'offrir l'électricité et le gaz à un prix "acceptable"", 30.08.2010.
[31] Prices for all communes can be found under http://www.strompreis.elcom.admin.ch/Start.aspx



Comments: Price with taxes
Source: http://www.strom.ch/de/dossiers/stromgrafiken.html (accessed on 30.11.2011)

Figure 2-4: Electricity price in Switzerland and EU-27 in 2010: household

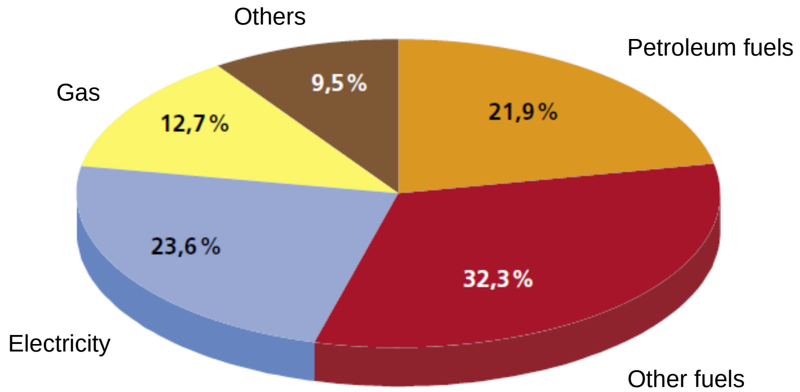


Comments: Price without VAT
Source: http://www.strom.ch/de/dossiers/stromgrafiken.html (accessed on 30.11.2011)

Figure 2-5: Electricity price in Switzerland and EU-27 in 2010: industry

2.2.2 Electricity statistics

Switzerland spends about 31 billion CHF per year for energy, which represents roughly 6% of the GDP (BFE, 2011b). As shown in Figure 2-6, Switzerland depends largely on imported fuels for its energy supply. However, once the fuels for the thermal plants are in Switzerland, the electricity supply is self-sufficient. Over a year, electricity imports and exports are balanced. In a simplified view, Switzerland exports electricity during summer and imports during the winter. It exports peak load energy and imports base load energy (more in Section 7.1.2). The amount of transit electric energy is about 100% of the domestic production. The role of an electricity hub is key to the well-functioning of the UCTE network.

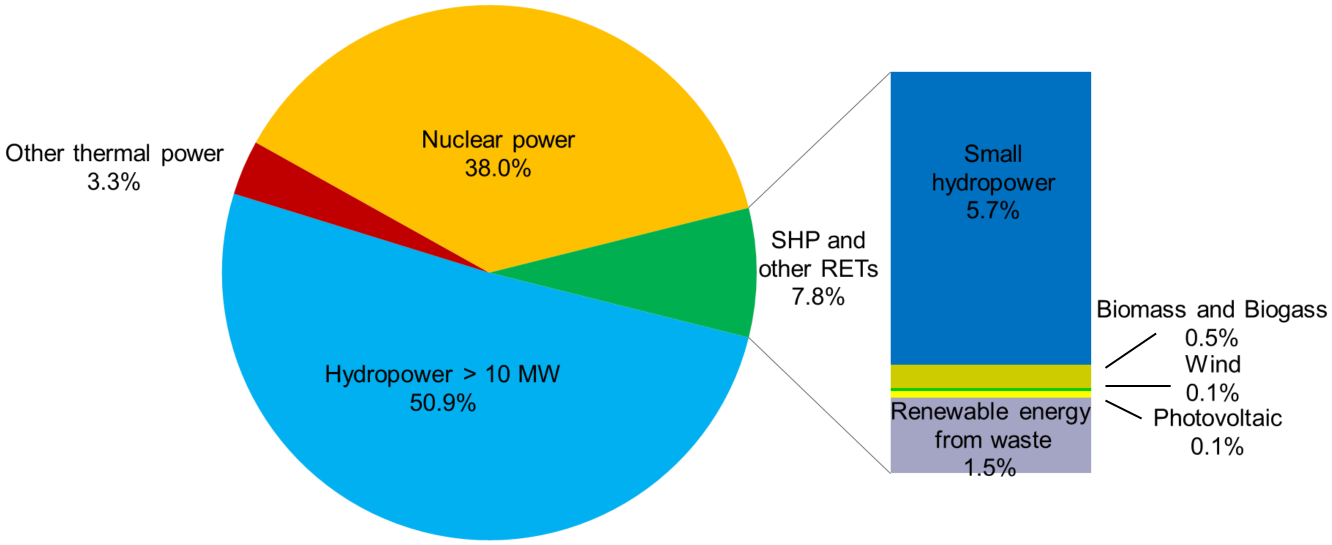


Source: (BFE, 2011b: 4)

Figure 2-6: Final Swiss energy consumption in 2010 according to the energy vectors

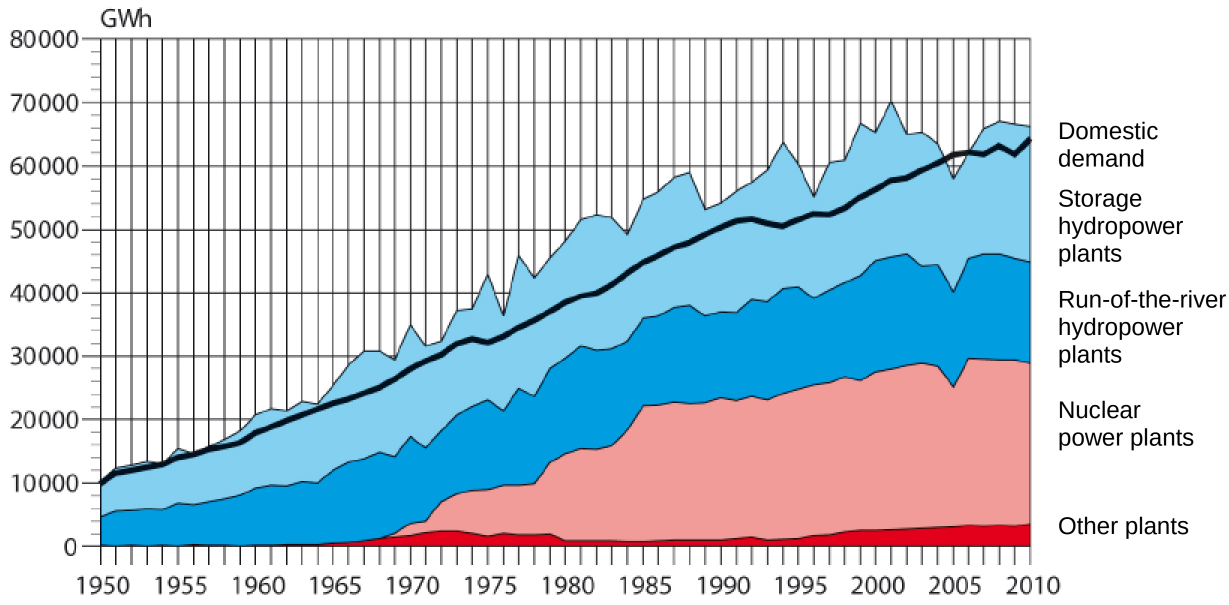
The electricity production mix is illustrated by Figure 2-7. It must be highlighted that the domestic production is almost CO_2 free. Therefore CO_2 emissions from the electricity sector per capita and per GDP are very low in Switzerland compared to neighbouring countries. About 60% of the electricity generation is renewable, with hydropower representing 57%, and nuclear power representing 38%. Small hydropower is by far the most important RET among the institutionally facilitated RETs (e.g., feed-in remuneration). Wind power and photovoltaic account for less than 0.2%, but will increase their contribution (see Section 2.3.1 and 7.2).

The increase in production and demand is shown in Figure 2-8, where it is highlighted that in the 1970s about 90% of the production was from hydropower. The hydropower production is split between run-of-the-river and storage plants (see also Section 4.1.2). Nuclear power started to feed into the grid in the 1970s with currently five plants producing electricity (last plant in operation since 1984). The supply followed the demand which continuously grew following to some extent the GDP growth.



Sources: (BFE, 2011g, 2011d, 2011e)

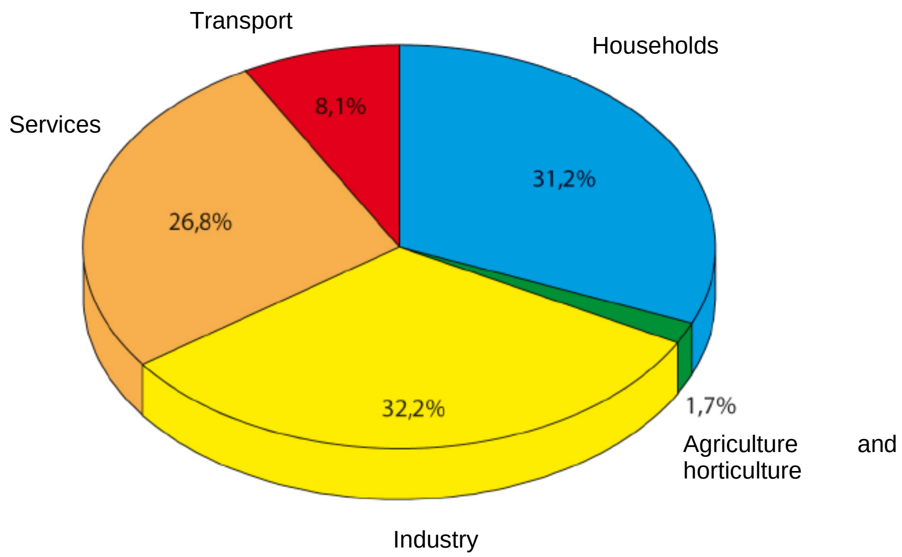
Figure 2-7: Swiss electricity production mix in 2010, total production of 66.3 TWh



Source: (BFE, 2011d: 15)

Figure 2-8: Swiss electricity production mix since 1950

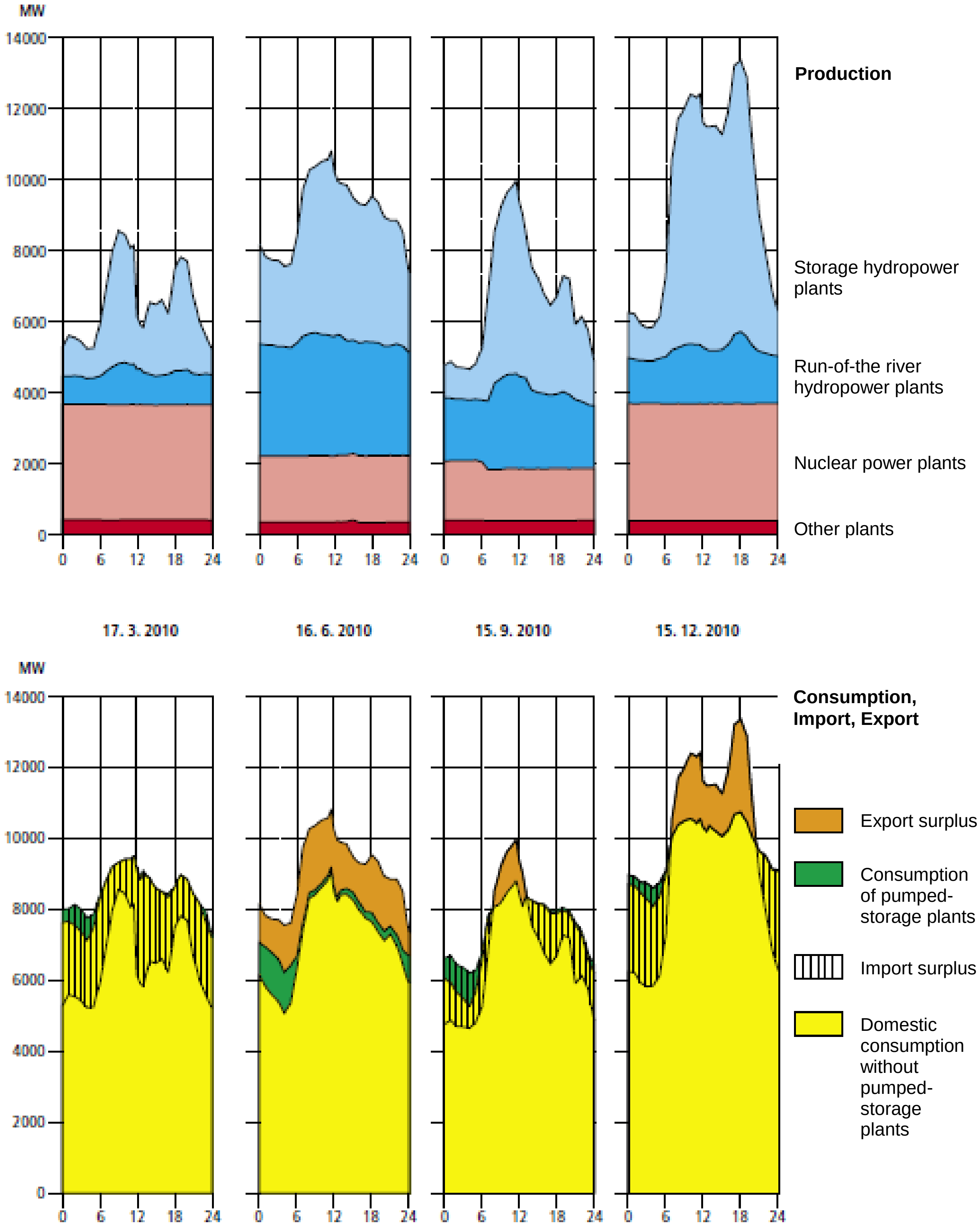
The electricity consumption is split between the following consumers in Figure 2-9. Households consume about 31%, the industry 32% and the services 27%. Transport accounts for 8%.



Source: (BFE, 2011d: 6)

Figure 2-9: Swiss electricity consumption in 2010, total consumption of 59.8 TWh

The electrical production and consumption is not constant over a time period. When taking a single day, there is peak usage at midday and during the winter there are clear peaks in evening usage. In Switzerland, the base load is ensured by the nuclear power and run-of-the-river hydropower plants, while the peak load is ensured by storage hydropower plants as shown in Figure 2-9. These profiles matter later in the research (see Chapter 7).



Source: (BFE, 2011d: 32)

Figure 2-10: Electricity consumption and production during the year in Switzerland

2.2.3 Electricity policy

Electricity policy in Switzerland is based on the energy articles in the Swiss Federal Constitution, the Energy Law, the CO_2 Law, the Nuclear Energy Law and the Electricity Supply Law (see also Table 5-2)[32]. Additionally, further policies have been established at Cantonal and Communal levels. Further to these legal bases, several energy programs and strategies have been developed at the Federal, Cantonal and Communal levels.

In 2001, the Federal council launched the SwissEnergy programme on the basis of the Energy Law and the CO_2 Law in collaboration with Cantons, municipalities, industry and environmental organisations. This program has a comprehensive strategy for promoting efficient energy use and the use of renewable energy in trade and industry, the buildings and mobility sector. The program, which followed the previous "Energy 2000" program, aims to make a valuable contribution towards Switzerland's climate and energy targets (see below) and to secure a sustainable energy supply for the country[33]. It includes SHP (see Section 5.2.2). The program has become an important driving force for innovation in the economy and is dominated by the idea of voluntarism. Its strength relies on the close co-operation between the Federal government, the Cantons and Communes, and numerous partners from trade and industry, environmental and consumer organisations, and public and private agencies. "SwissEnergy" is stated to continue for a second decade to 2020.

In 2007, the Federal council decided to focus its energy policy on four main pillars: energy efficiency, renewable energy, replacement of existing large scale power plants and construction of new ones, and foreign energy policy. Several action plans (e.g., for the use of renewable energy) were established, which set out, among other goals, to increase the proportion of renewable energy in the overall energy consumption by 50 per cent from 16% to 24% between 2010 and 2020 (EnergieSchweiz, 2008). One of the seven measures is the facilitation of hydropower, including MHP and SHP (BFE, 2004). This will contribute to reach the target in the Energy Law for 2030 of 5'400 GWh a year more electricity from RETs compared to 2000 (2'000 GWh of this amount should be from hydropower[34], 1'100 GWh from small hydropower (BFE, 2008c)).

Beside the energy target in the Energy Law, the CO_2 Law defines binding targets for the reduction of the greenhouse gas, CO_2. The targeted reduction is primarily to be achieved through voluntary measures on the part of companies and private individuals, as well as with the aid of measures relating to energy, environment, transport and financial policy. It doesn't affect so far the electricity sector (see Section 6.6).

Since the end of 2007, negotiations have been occurring between Switzerland and the EU concerning a bilateral electricity agreement. Originally, it concerned the security of supply in the liberalised electricity sector, the cross-border electricity trading, electricity related environmental aspects and mutual market access. In 2010, it has been enlarged to include renewable energy issues. Switzerland being an electricity hub means it must be involved in the on-going changes caused by the EU policy related to the electricity sector, which explains the negotiations. The further merged former national electricity sectors will enable more efficient ancillary services and an overall better operation of the grid. But the institutional uncertainties have to be reduced in order to lower risks and encourage investments needed to supply the electricity demand and reinforce the grid.

In May 2011, following the accident at the Fukushima nuclear plant in Japan in March 2011, the Federal council decided to phase out of nuclear power in Switzerland. The council declared that the medium term security of electricity supply will be guaranteed without nuclear power[35]. It also declared that all existing nuclear power plants should be decommissioned at the end of their safe operational lifespan, which is currently evaluated at around 50

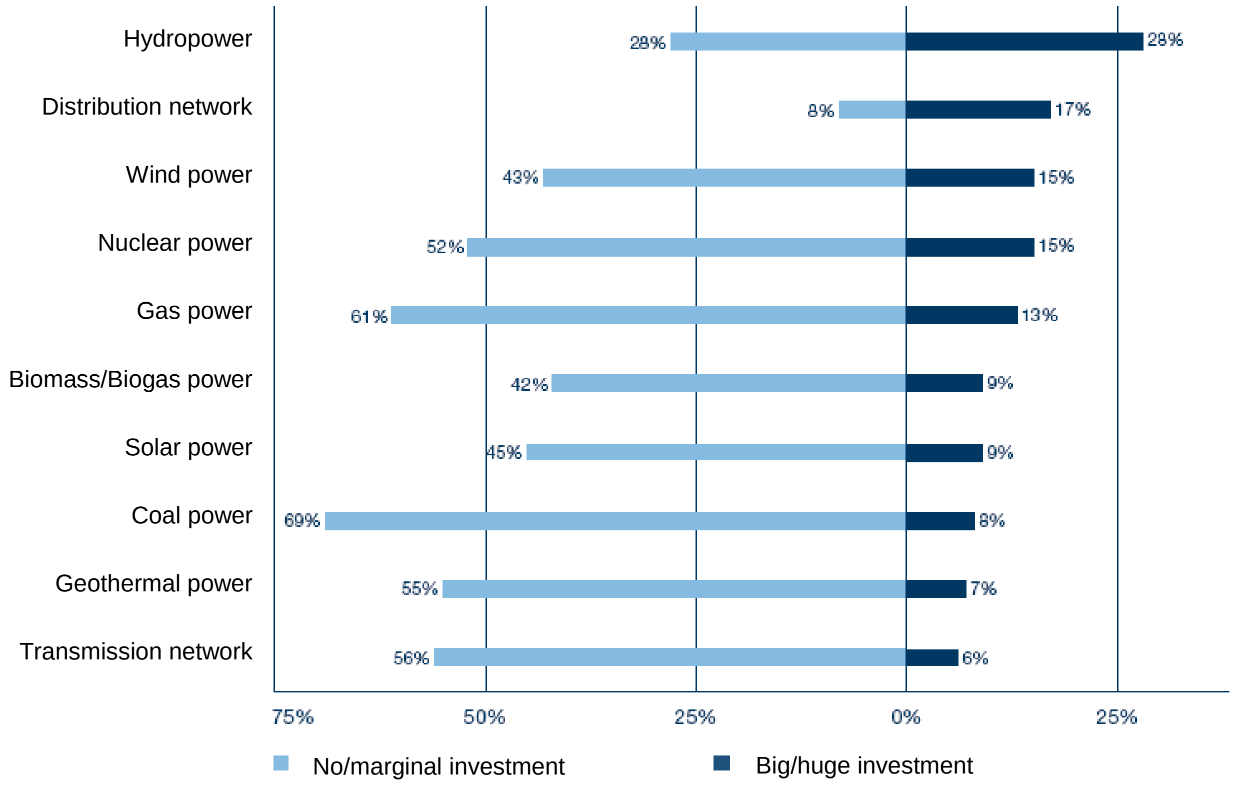
[32] All documents can be found under http://www.admin.ch/ch/e/rs/rs.html, except the Federal Constitution which is under http://www.admin.ch/ch/e/rs/c101.html (Articles 89-91).
[33] SwissEnergy website: http://www.energieschweiz.ch/de-ch/home.aspx (accessed on 27.02.2012)
[34] Art. 1 of the Federal Energy Law http://www.admin.ch/ch/d/sr/730_0/a1.html (accessed on 27.02.2012)
[35] Press release 25.05.2011 : http://www.bfe.admin.ch/energie/00588/00589/00644/index.html?lang=en&msg-id=39337

years, and not be replaced by new nuclear power plants. Therefore, the first plant would be taken off the grid in 2019 and the last one in 2034.

In order to guarantee the security of electricity supply, the Federal council revised its energy strategy (see next Section). It identified measures which are intended to ensure that the supply of electricity in Switzerland remains of high quality and reliability, as well as largely free from CO_2. In addition, the Federal council declared that the prices should remain competitive.

The Federal parliament passed several motions on this topic following the Federal council decision[36]. These motions affect the future perspectives of the electricity sector in Switzerland and will strengthen the role of hydropower (see next Section). As the phasing out of nuclear power and its associated measures are major changes in the energy policy, they will most probably have to be submitted to one or several public votes.

Hydropower was seen as a priority to invest in before the revision of the energy policy following the Fukushima accident. A survey conducted in Switzerland in 2009 was asking the electricity utilities the following question: which entrepreneurial strategies and investments need to be taken within the sector in order to be able to cope within the liberalised market structure and in economic difficult times? The suggested priorities are shown in Figure 2-11.



Source: (PricewaterhouseCoopers, 2009: 11)

Figure 2-11: Survey results among Swiss electricity utilities concerning which priorities to invest in

[36] See for example the program of the Council of States on 28.09.2011 and Nation Council on 6.12.2011: www.parlement.ch

2.2.4 Perspectives

Sustainable energy supply will require a further shift to electricity as energy vector (Püttgen, 2010). Visions such as the 2'000-Watt society (Stulz, Tanner et al., 2011) describe possible paths. This vision developed by Novatlantis targets a society where each citizen consumes the equivalent of 2'000 Watt of primary energy and evolved to include a 1 tonne of CO_2 emissions per capita per year[37].

Concerning the development of the electricity networks, there are various scenarios. Taking the ones developed for the UK for 2050 (see Table 2-1), Pollitt states that micro-grids and energy service companies will challenge the current business model of distribution network operators. The final customers will be much more involved, the share of distribution charges in the total energy bill reduced and more local responsibility will be required to reach energy and climate targets (Pollitt, 2010). The observations can be applied to other countries as well, such as Switzerland. Further comments concerning so called micro-grids or "smart grids" are provided in Section 3.2.3.

Table 2-1: Scenarios for Great Britain electricity networks in 2050

Scenario	Description
Big Transmission and Distribution	Transmission system operators (TSOs) are at the centre of network' activity. Network infrastructure development and management continues as expected from today's pattern, while expanding to meet growing demand and the deployment of renewable generation.
Energy Services Companies	Transmission and distribution networks are required to support a much more vibrant energy services market place with 'super-suppliers' or energy service companies (ESCOs) taking a central role between the customers and the transmission and distribution network operators.
Distribution System Operators	Distribution system operators take on a central role in managing the electricity system. Compared to today, distribution companies take much more responsibilities for system management, including generation and demand management, quality and security of supply, and system reliability, with much more distributed generation.
Micro-grids	Consumers are at the centre of activity in networks. The self-sufficiency concept has developed very strongly in power and energy supplies. Electricity consumers take much more responsibilities for managing their own energy supplies and demands. As a consequence, micro-grid system operators emerge to provide the system management capabilities to enable customers to achieve this with the new technologies.
Multi-purpose networks	Network companies at all levels respond to emerging policy and market requirement. TSOs still retain the central role in developing and managing networks, but distribution companies also have a more significant role to play. The network is characterised by diversity in network development and management approaches.

Source: (Ault, Frame et al., 2008)

[37] http://www.novatlantis.ch/2000watt.html (accessed on 27.02.2012)

Independently of the development of the electricity network, Switzerland faces challenges in its electricity production. There will be an electricity gap between the domestic production and demand between 2020-2025 (BFE, 2007a; ECG, 2009; Püttgen, 2011). This is because the nuclear power plants within Switzerland are reaching their end of use (26 TWh/year less production in 2035), the long term purchase contracts of electricity with France are coming to an end (12 TWh/year less in 2035), and there remains an increasing demand for electricity (Püttgen, 2011).

The Swiss society will consume more and more electricity per capita in order to reduce its energy consumption and CO_2 emissions per capita. For example, electrical mobility (hybrid and electrical cars for private and public use) will replace part of the fossil-fuelled mobility and electric heat pumps will replace fossil-fuelled heating installations, reducing CO_2 emissions and overall energy consumption. The increase in electricity demand is therefore mainly triggered by these changes in energy vectors and by the population growth, as well as by the growing part of ICT equipment. However, energy efficiency (see also below) should help to reduce this increase, although it will probably not eliminate it.

In the energy scenarios of the SFOE in 2007, the scenario III, which was already ambitious regarding limiting the increase in demand, evaluated the electricity demand in 2035 at 60 TWh/year. This would be an increase of 13% compared to 2000. Already in 2010, the increase had been 12.7% compared to 2000 reaching a consumption of 59.8 TWh. Therefore, during the next 25 years the increase should only be of 0.3%, corresponding to 0.2 TWh a year. This would mean that any additional growth would have to be compensated by energy savings through energy efficiency (Püttgen, 2011). Most scenarios predict a stabilisation of the electricity demand at the horizon of 2035 between 60 and 90 TWh/year (VSE-AES, 2006; BFE, 2007a; ECG, 2009; BFE, 2011c).

The periodically prepared energy perspectives (the major last one done in 2007 (Energy Perspectives 2035 (BFE, 2007a)) have been revised following the Fukushima accident and the associated decision of the Federal council. The revision led to the Energy Perspectives 2050 and the Energy Strategy 2050 (BFE, 2011c). The Energy Perspectives 2050 forecast a consumption of 86.3 TWh a year in 2050 (an increase of 62% compared to 2000). Three electricity provision scenarios were developed:

1) Continue with the current electricity production with early replacement, if necessary, of the three oldest nuclear power plants to ensure the highest level of safety: It is the continuation of the energy policy of the four pillars described in Section 2.2.3. In the long term, the two oldest nuclear plants are also decommissioned. If the replacement is not achieved with nuclear power, then gas-fired combined cycle plants (GCC) will have to be used between 2017 and 2050.
2) Existing nuclear power plants will not be replaced at the end of their technically safe operating period: The current energy policy is continued and nuclear power is replaced by an optimised mix of hydropower, other RETs, cogeneration facilities, GCC and electricity imports (the latter mainly between 2025-2045). Hydropower becomes very significant and has to be expanded accordingly. CO_2 emissions within the energy sector are not increasing thanks to adequate compensation measures. The electricity grid has to be upgraded and additional flexible generation and energy storage is required in order to integrate the increase of RETs production.
3) Accelerated phasing out of nuclear power: Existing power plants will be shut prior to the end of their safe operating life. The existing nuclear power plants will be decommissioned without replacement after the 40-year operating period ends. Hydropower, other RETs and GCC production have to be greatly expanded. In the medium to long term, use of GCC plants will also have to increase and substantial amounts of electricity have to be imported. CO_2 emissions increase. The grid has to be reinforced for the imports and the integration of new production from RETs.

The Federal council decided to go along scenario 2) which requires a new energy policy underpinning the aim to reach the 2'000 Watt and 1 t CO_2 society (Bundesrat, 2011). Energy efficiency, saving 24.4 TWh/year, and the facilitation of RETs, adding 24.4 TWh/year, are at the core of the new energy policy. 37.5 TWh/year is provided by the remaining existing power plants (mainly hydropower) to cover the demand. In order to reach these targets, the new Energy Strategy 2050 includes: command&control and market-based instruments[38] to increase energy efficiency; market-based instruments (mainly the FIR) to facilitate RETs; the development of cogeneration plants before GCC plants; maintaining electricity imports; expanding the grid; strengthening energy research; public entities taking the lead by example; and encouraging international cooperation such as a bilateral agreement with the EU and a more active participation within the international energy debates. The Energy Strategy 2050 is being refined until spring 2012 and will be in public consultation until middle of 2012[39].

A few issues have to be discussed at this point. Firstly, energy efficiency should not just be promoted at the consumption level (e.g., refrigerator energy label), but also at the production and transport levels (see also Section 6.2). The overall efficiency of primary energy transformation to the final energy has to be increased. Furthermore, energy wasting has to be avoided (e.g., standby mode of electrical equipment[40]). However, the so-called "rebound effect" must be considered when evaluating energy efficiency measures. The rebound effect refers to the effect that consumers, when buying a more energy efficient equipment, tend to increase the size of the equipment or use it more, thus in certain cases not decreasing their energy consumption (Greening, Greene et al., 2000). E.g., one buys a new television which consumes less for the same size, but one gets a bigger size than before.[41]

Secondly, EU regulation will not allow long-term import contracts with France to be renewed, and the European Commission may even force early termination. In addition, with the German nuclear phase out, there are other major countries within Europe importing electricity. The argument that Switzerland can import wind power from the North requires the construction of new power lines through Germany. However, why should the German agree to such lines when in Switzerland discussions have been on-going for the last 20 years for a new power line of only 30 km (Püttgen, 2011). Furthermore, it must be mentioned that the EU Lisbon treaty mentions that in the case of critical energy supply, the EU member states must be supplied before other states[42]. Therefore securing imports of electricity for Switzerland could become much more difficult.

Thirdly, gas-fired plants will not be operational before 2013 (i.e., post-Kyoto context[43]) and are only legally feasible if adequate ecological provisions, such as CO_2 compensations, are taken into account (see Section 6.6). If an installed capacity beyond 1.5 GW is built in Switzerland, which corresponds to about three to four GCC plants or about half of today's nuclear power capacity, then the existing gas pipelines have to be upgraded (Püttgen, 2011). One of the latest studies evaluates the need of additional electricity generation at five GCC plants with an installed capacity of 550 MW each, which results in a total capacity of 2'750 MW[44]. Furthermore, certain doubts remain concerning the gas supplying nations. However, the GCC plants might be required to fill the production gap before the targeted production from RETs is reached.

[38] See Section 5.2.2 for explanation on command&control and market-based instruments.
[39] http://www.news.admin.ch/message/index.html?lang=de&msg-id=42478 (accessed on 01.12.2011)
[40] For example, the standby mode of electrical equipment consumes 15% electricity at household level in Geneva (http://www.eco21.ch/eco21/particuliers/ecogestes/stand-by-et-consommation-cachee.html (accessed on 27.02.2012)).
[41] A recent study touching on energy efficiency can be found under: http://www.strom.ch/de/extensions/news/news-ansicht/news/urbanisierung-beeinflusst-stromnachfrage-der-haushalte.html?cHash=80812f36e023d35c417ffc50dd87b0d8 (accessed 09.03.2012)
[42] Lisbon treaty, Article 122
[43] See Section 6.6. For more information on the Kyoto protocol, which includes several flexible mechanisms such as the emissions trading and Clean Development Mechanism (CDM), see http://en.wikipedia.org/wiki/Kyoto_Protocol (accessed on 12.12.2011).
[44] Dow Jones Newswires, "Analyse: Schweiz bleibt auf Energieimporte angewiesen". Referring to PROGNOS. 01.11.2011.

Fourthly, cogeneration plants have a significant potential in Switzerland. They should be further developed especially as they combine the heat and electricity generation in winter when there is need for heating and less electricity production from solar photovoltaic. However, the cogeneration development has to be aligned with the climate targets. CO_2 emissions have to be compensated if the fuel is not renewable (e.g., not biomass or biofuel). The deployment of cogeneration plants at large scale will require some decades.

Finally, the electricity production from RETs has to be increased. The different RET potentials are discussed in the next Section, except for large hydropower. Large hydropower has a small remaining potential of about 0.5 – 1.6 TWh/year[45]. New feasible sites are very limited, but some dams can be heightened and existing plants upgraded. Furthermore, there remains potential for pumped-storage plants (see Section 7.1.2).

In summary, the contributions of future GCC plants and electricity imports to cover the domestic electricity demand remain uncertain. Large hydropower will increase, as well as cogeneration in the production of electricity. In any case, the production from RETs has to significantly increase if the new energy policy is implemented. The electricity demand has not only to be covered in 2050, but already in 2020 when the first nuclear plants will be off the grid and 2035 when all existing nuclear plants will be decommissioned.

2.3 Renewable energy technologies for electricity generation in Switzerland

As introduced above, the Federal council wants to increase the amount of RETs within the electricity production, including SHP. This Section presents an overview of the different RETs with the more detailed case of SHP following in Chapter 4.

2.3.1 RET potentials in Switzerland till 2035 and 2050

Table 2-2 summarises the expected potential in 2035 and 2050 for the different RETs. It has been compiled from several sources including the SFOE and the EnergieTrialogSchweiz, an interdisciplinary group of 200 personalities from science, society and economy[46]. The potential of large hydropower was discussed in Section 2.2.4 and the potential of SHP is studied in Section 4.2.2. The fastest growing RETs are photovoltaic and wind power (see also Figure 2-12). The growth of geothermal power could be significant as well.

Table 2-2: Expected domestic potentials of RETs in 2035 and 2050

RET	Production in 2010 [TWh]	Potential in 2035 [TWh]	Potential in 2050 [TWh]
Photovoltaic	0.08	1.0 – 2.0	8.0 – 12.0
Wind power	0.04	1.0 – 2.0	2.0 – 4.0
Biomass[1]	1.28	5.0	5.0
Small hydropower	3.77	5.1	5.2 – 5.6
Geothermal power	-	0.0 – 0.5	1.5 – 4.0
TOTAL	**5.17**	**12.1 – 13.6**	**21.7 – 30.6**

[1] including energy from waste from renewable resources

Source: Adapted from (Energie Trialog Schweiz, 2009), for 2050 (BFE, 2011c), and for SHP see Section 4.2.2.

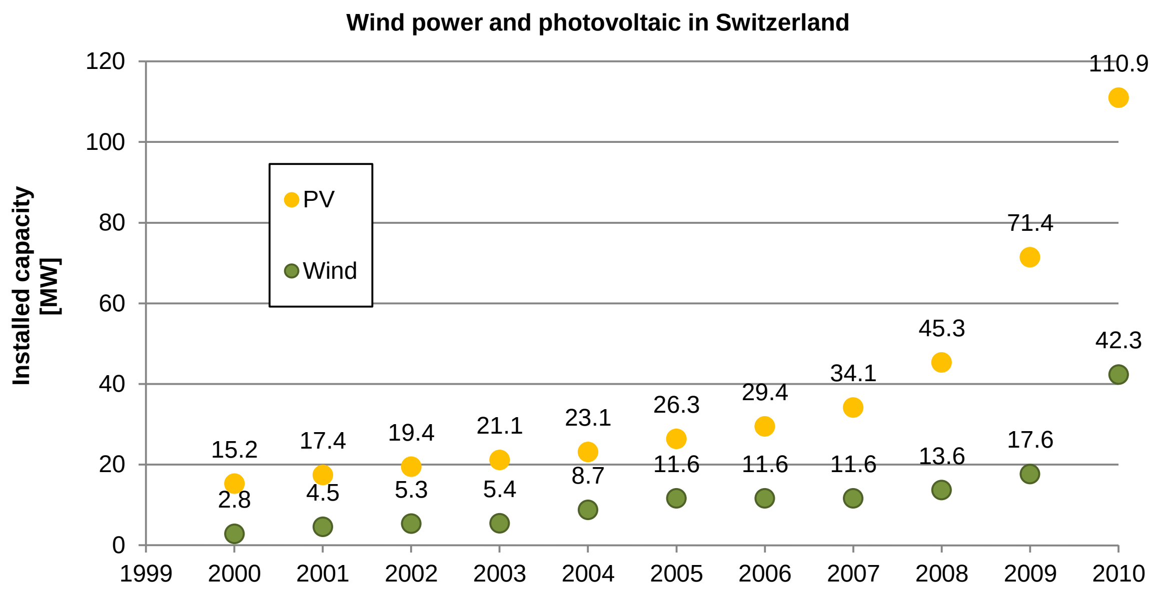
[45] Discussion at the Workshop “Energiestrategie 2050: Wasserkraftpotenzial der Schweiz”, Bern, 15.11.2011, and Presentation of the results of the survey “Wasserkraftpotenzial der Schweiz”, SFOE, Ittigen, 14.02.2012. New residual flow regulation is considered.

[46] http://www.energietrialog.ch/ (accessed on 27.02.2012)

According to the Swiss Academy of Engineering Science, 6'000 MW of peak capacity of photovoltaic can be installed until 2050 producing approximately 5.7 TWh. This is slightly less than what the EnergieTrialogSchweiz suggests (SATW, 2007: 12) and clearly less than what the SFOE suggests (see Table 2-2). It corresponds to 10% use of the Swiss roof surface (30 km^2). This electricity would be mainly available during the summer when Switzerland is already exporting electricity. The feasible potential of photovoltaic remains under discussion.

Wind power can be developed at several sites (see (BFE and BAFU, 2004; BFE, BAFU et al., 2010)), but there remains a strong opposition which is often very local. A windmill of 2 MW, such as the one installed on Mont Crosin, produces approximately 4 GWh/year. To reach the lowest scenario of 1.0 TWh/year in 2035, 250 new windmills of 2 MW need to be installed. In November 2011, there were 30 windmills in Switzerland[47].

Both, photovoltaic and wind energy, are intermittent energy sources. They produce with cyclical and unpredictable fluctuations. Their total installed capacity significantly increased in Switzerland during the last two decades as shown in the Figure 2-12. The more plants there are using intermittent sources to feed electricity into the grid, the more adjustment capacities, such as hydropower storage, and the more information on the electric energy flows are necessary. This will be further developed in Section 7.2.



Source: (BFE, 2011e)

Figure 2-12: Wind power and photovoltaic in Switzerland in 2000-2010

The use of waste of renewable resources as biomass for electricity generation will further increase as well. It offers a growth option of about 50%. In addition, traditional biomass offers as well some potential for expansion as shown in Table 2-2.

The potential of geothermal power for electricity generation is limited. This source is more appropriate for heat generation. Electricity could mainly be generated by deep geothermal power. New projects are currently under consideration in several Swiss cities.

The new energy policy linked to the Energy Strategy 2050 aims at generating 24.4 TWh/year more from RETs until 2050. Taking the figures from Table 2-2 this seems feasible, although optimistic, as the evaluated additional

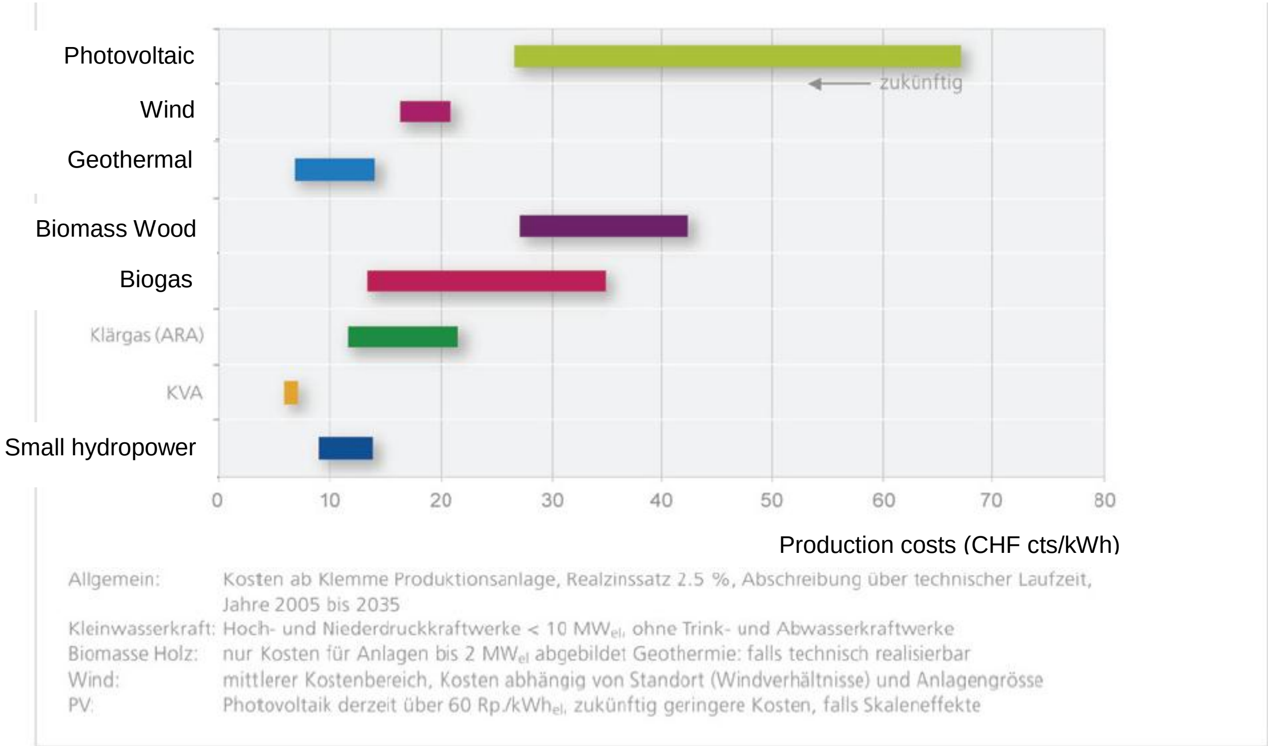
[47] http://www.suisse-eole.ch/uploads/media/Faktenblatt-Windenergie-111111.pdf (accessed on 01.12.2011)

potential is between 16.6 and 25.5 TWh/year to which about 0.5 – 1.6 TWh/year from large hydropower can be added (see Section 2.2.4). The expansion of RETs for electricity production comes with certain costs.

2.3.2 The approximate production costs per RET

The exploitation of the potentials is related to the costs per RET. Within the Energy Perspectives 2035, the costs have been evaluated as shown in Figure 2-13 (more details for SHP in Section 4.1.3). It has to be noted that the use of fossil energy sources, such gas and coal, and nuclear will become more expensive as their reserve decrease and the extraction becomes more difficult. Therefore, RETs will become more and more of economic interest. In addition, if a cost-benefit-analysis was conducted taking into account the social impact (e.g., public costs in case of catastrophes) and environmental aspects (e.g., CO_2 emissions) as well as the economic scope, RETs would appear in an even more favourable light (see also Section 2.3.3). However, currently, RETs requires institutional facilitation to be implemented under financially viable conditions (see Chapter 5).

The investment and O&M costs of RETs are strongly influenced by the quality and availability of the resources used, the location and access to the electricity grid. "Non-technology costs factors" such as administrative, financing and insurance costs matter as well (Dinica, 2011).



Source: (BFE, 2007a, Fig. 3.2-3)[48]

Figure 2-13: Average production costs (including financial costs) of RETs between 2005-2035

The production cost estimates of photovoltaic in Figure 2-13 have to be taken with caution. The costs are decreasing by 15-22% each time the installed capacity doubles (IEA, 2010). Therefore, exact estimates until 2035 are difficult to evaluate.

[48] Figures for the EU-27 can be found in (Haas, Panzer et al., 2011)

In order to update the cost estimates in Figure 2-13, the current average costs covered by the FIR scheme can be used. Table 2-3 shows the average costs per RET. Photovoltaic will continue to decrease in costs, wind power is already within the cost estimates of Figure 2-13, biomass could become more expensive and SHP could reduce some costs with further innovation (see Section 4.1.6).

Table 2-3: Average costs per RET in 2009 and 2010

RET	Average costs 2009 [cts/kWh]	Average costs 2010 [cts/kWh]
Small hydropower	16.59	16.52
Photovoltaic	71.51	68.12
Wind power	18.59	18.59
Geothermal power	-	-
Biomass	18.63	20.65

Source: Stiftung KEV, Geschäftsbericht 2009 and 2010, www.stiftung-kev.ch

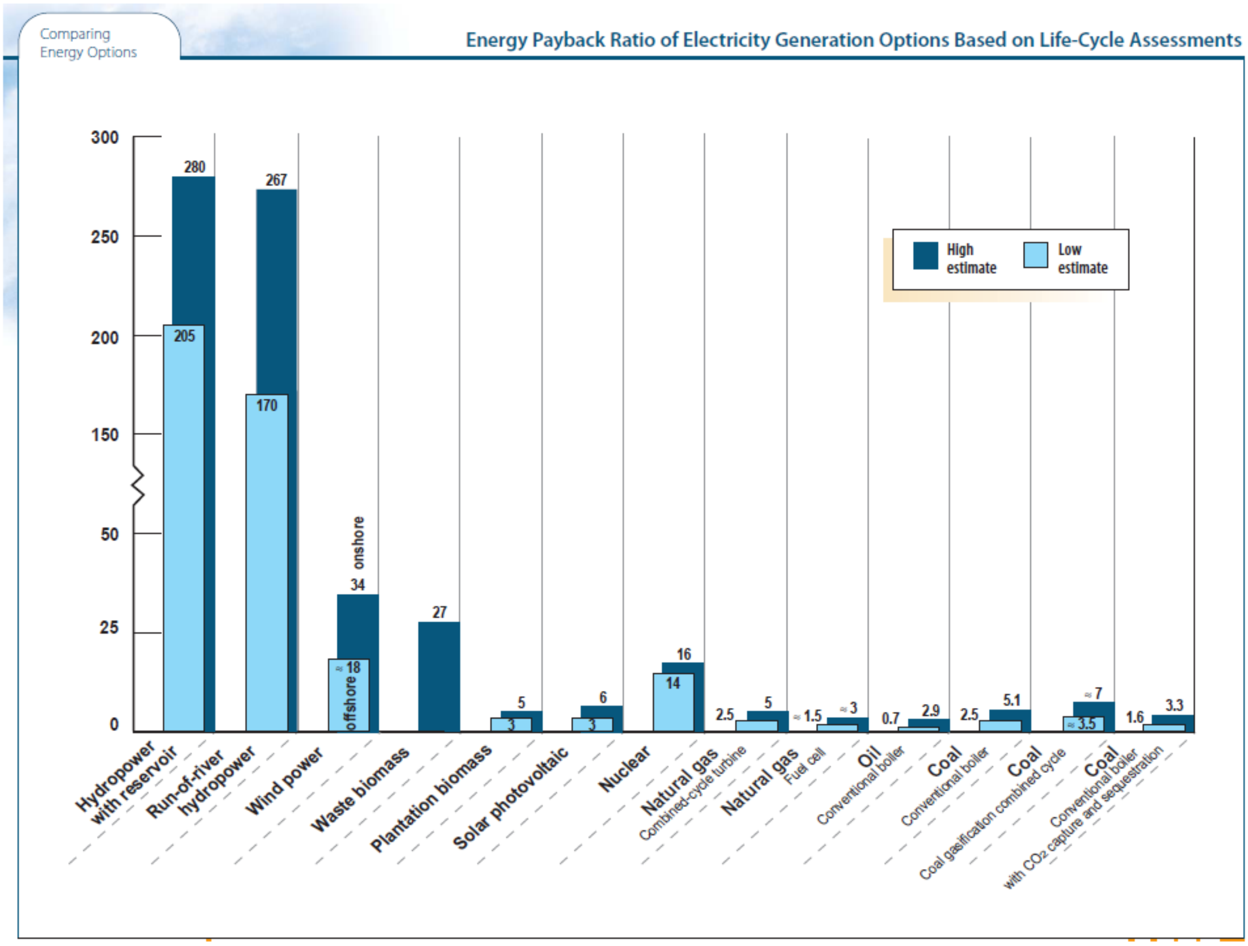
These production costs have to be compared to current average electricity production costs. In the example given for the electricity supply in Lausanne (see Section 2.2.1) the production costs are about 10 cts/kWh. The costs of the RETs remain and are still significantly more expensive than the costs of the current production mix.

2.3.3 Energy payback ratio and GHG emissions of RETs

For each electricity generation technology, the “energy payback” is defined by the Equation (2-1).

$$Energy\ paypack\ ratio = \frac{Energy\ production\ during\ life\ span}{\sum Energy\ required\ to\ (build, maintain, fuel\ the\ generation, deconstruct)} \tag{2-1}$$

If a technology has a low payback ratio, much energy is required to build and maintain it and this energy is likely to produce major environmental impacts. The payback ratios do vary significantly for RETs due to variable site conditions (e.g., topography and hydrology in the case of hydropower, quality and quantity of the wind in case of wind power, intensity of solar radiation for solar power). Figure 2-14 gives an overall view not solely for RETs, but for fossil fuel and nuclear electricity generation systems as well.



Source: (Gagnon, 2005: 2)

Figure 2-14: Energy payback ratio of electricity generation technologies

The technological development of solar photovoltaic leads to significantly better energy payback ratio today than in 2005. According to the PV-Lab at EPFL[49], the ratio is between 10-20 in 2011. Figure 2-14 has therefore to be taken indicatively.

The energy payback ratio is also linked to the degree of usage of the plant. Skoglund developed a corresponding indicator which is the ratio between the average annual electric energy production and the hypothetically annual production if the plant would have produced at all times at full capacity. Examples give a degree of usage on average for photovoltaic of 10%, for wind between 20-30% and for SHP generally above 30% (Skoglund, Leijon et al., 2010).

Another major advantage of RETs is their low GHG emissions per produced electricity unit. Table 2-4 shows indicative figures for various technologies. SHP belongs to the technologies with the lowest emissions.

[49] Prof. C. Ballif, Cours des Energies Renouvelables, EPFL, Lausanne, 24.05.2011.

Table 2-4: Lifecycle gCO_2e/kWh emissions estimates for electricity generators

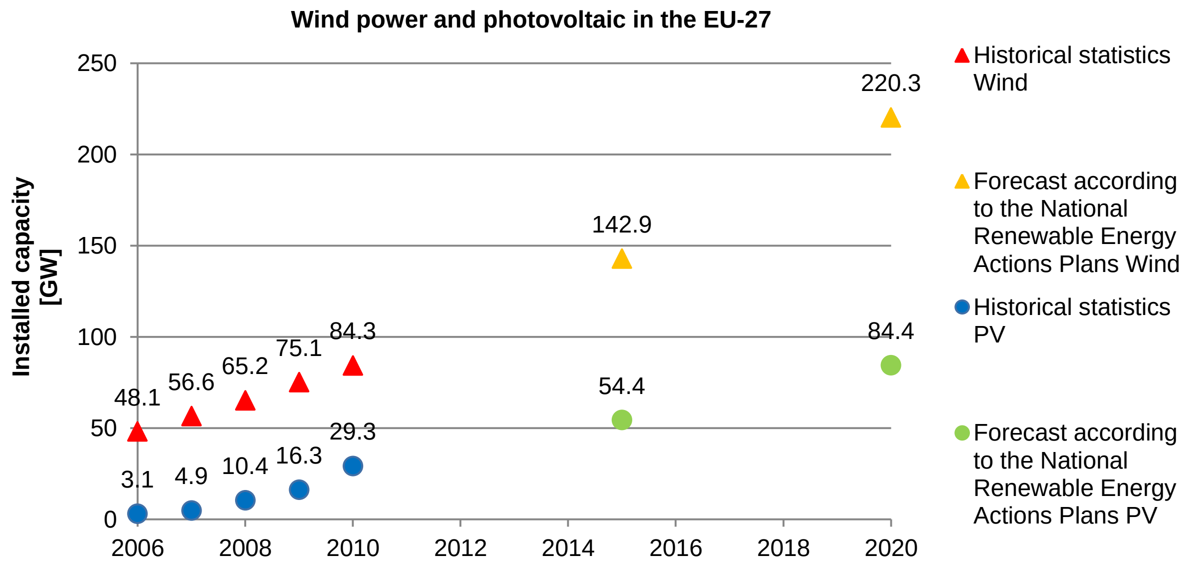
Technology	Capacity/configuration/fuel	Estimate (gCO_2e/kWh)
Wind	2.5 MW, offshore	9
Hydroelectric	3.1 MW, reservoir	10
Wind	1.5 MW, onshore	10
Biogas	Anaerobic digestion	11
Hydroelectric	300 kW, run-of-river	13
Solar thermal	80 MW, parabolic trough	13
Biomass	Forest wood co-combustion with hard coal	14
Biomass	Forest wood steam turbine	22
Biomass	Short rotation forestry co-combustion with hard coal	23
Biomass	Forest wood reciprocating engine	27
Biomass	Waste wood steam turbine	31
Solar PV	Polycrystalline silicone	32
Biomass	Short rotation forestry steam turbine	35
Geothermal	80 MW, hot dry rock	38
Biomass	Short rotation forestry reciprocating engine	41
Nuclear	Various reactor types	66
Natural gas	Various combined cycle turbines	443
Fuel cell	Hydrogen from gas reforming	664
Diesel	Various generator and turbine types	778
Heavy oil	Various generator and turbine types	778
Coal	Various generator types with scrubbing	960
Coal	Various generator types without scrubbing	1050

Source: (Sovacool, 2008: 2960)

2.3.4 Final remarks

RETs are often considered as distributed and decentralised production technologies. However, the question remains as to what exactly is a distributed or decentralized technology. Is distributed generation 100 kW or 10 MW installed capacity? Pepermans et al. define distributed generation along various indicators (2005), whereby the voltage level and installed capacity can be seen as the most important ones. Distributed generation is close to the consumption places, at lower voltage level and small scale. Decentralised generation on the other hand relates more to the way the grid is operated. But the exact definitions remain vague (Pepermans, Driesen et al., 2005). In any case, it can be observed that with more RETs feeding into the grid, more flows within the network become two-way instead of one way (Economides, 1996).

The institutional facilitation causes a significant increase in the production from intermittent RETs across Europe, as shown below in Figure 2-15 for wind power and photovoltaic. Within the liberalised electricity market, Swiss electricity suppliers can sell electricity from RETs from neighbouring countries and are thus affected by these expansions. In addition, the energy storage and flexible production capacities to integrate this growing intermittent electricity production may develop across the continent and thus involve capacities in Switzerland.



Source: http://www.eurobserv-er.org

Figure 2-15: Installed photovoltaic and wind power capacity in the EU-27

Finally, should the bilateral agreement on electricity between the EU and Switzerland include the part on RETs (i.e., RES-directive[50]), then Switzerland would have to significantly increase new RET facilitation before 2050. As the directive aims at 20% from renewable sources in its gross final consumption for 2020 among the EU, certain countries such as Sweden and Austria have to go beyond the 20% (49%, respectively 34%). Switzerland being similar to Austria, it can be assumed that a similar target would be used. Switzerland's current target for 2020 is 24% (see Section 2.2.3) and its current share is 19.4% (BFE, 2011e), whereby it was 16.9% in 2006. Significant more effort would thus be required.

Conclusion

Network industries such as the electricity sector are essential for society. They are complex industries where both institutions and technologies have to be taken into account when research is conducted. In the case of the electricity sector, the approach cannot solely focus on one technology, but has to consider the whole system. On the institutional side, the liberalisation process is a major change and its impact on RETs has often been neglected (Haas, Panzer et al., 2011) and clearly needs more research. The liberalisation process favours distributed and small scale generation (see Section 3.2.3). The case of SHP will be further elaborated in the next Chapters.

The latest energy strategy in Switzerland includes the phasing out of nuclear power. The electricity production from RETs, and especially hydropower, will have to be increased in all considered scenarios. SHP has thus an important role in the future generation mix.

SHP has some key advantages compared to other production technology which will be further elaborated in Chapter 4. In order to introduce SHP from the technological and institutional perspective, the theoretical literature and framework is introduced beforehand.

[50] http://www.managenergy.net/resources/48 (accessed on 02.12.2011)

3. Co-evolution and coherence between institutions and technologies in network industries

The literature on co-evolution and coherence in network industries is chosen as theoretical literature because it deals with, among other things, the electricity sector and with the liberalisation process in network industries (Künneke and Finger, 2007; Raven, 2007; Bolton and Foxon, 2010; Künneke, Groenewegen et al., 2010). To analyse network industries a theoretical framework, which includes the consideration of technologies as well as their interaction with the institutions, needs to be used (see Section 2.1). The coherence framework was chosen as the main theoretical framework within this research because it bridges the gap between engineering which focuses on technological aspects and institutional theory which focuses on institutional aspects (see also (Künneke and Finger, 2007)).

Furthermore, the coherence framework as part of the co-evolution literature (see Figure 3-1) has never been used to analyse small hydropower (SHP). Most literature relates to network industries as a whole and no literature analyses SHP from the perspective of co-evolution and coherence between institutions and technologies. This research on SHP using the coherence framework allowed a concrete application of the framework and contributed towards its improvement. The research of this thesis sheds a new light on SHP as part of the electricity sector. The framework guides and shapes the analysis of SHP. The specificities of the whole network industry are also taken into account.

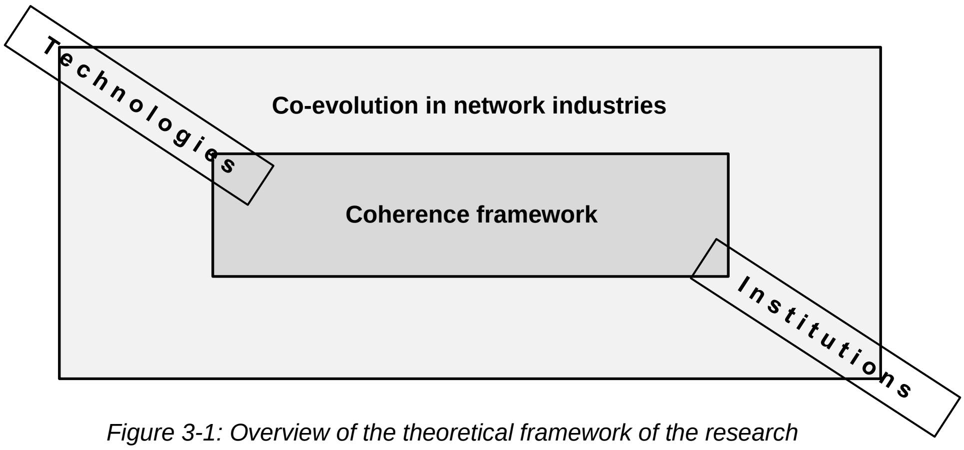


Figure 3-1: Overview of the theoretical framework of the research

The Chapter defines the terms technology and institutions as well as the theoretical context. The literature on co-evolution is presented, followed by the coherence framework. The initial framework and its latest development are discussed.

3.1 Theoretical context

Saviotti defines **technologies** as *"the set of activities by means of which human beings modify their external environment"* (2005, p. 12). These "activities" mostly refer to technical artefacts and do not include ideas. In a more general sense, the Oxford Dictionary (Hornby, 2000) defines technology as the *"scientific knowledge used in* *practical ways in industry"*. It is linked to the use of tools and crafts. The boundaries of the technologies are physically given.

Within this research small hydropower represents the technology (see Chapter 4), whereby in a larger perspective the technology is the whole electricity sector (generation, transport, distribution; see Section 2.2). This larger view matters for example in regards to the continuous and instant adjusting of electricity demand and supply.

Institutions have been defined in various ways (Williamson, 2000). Many scholars in the literature have different understanding of institutions, primarily based on their background in economics and social sciences (Nelson and Sampat, 2001). The most common view of institutions is to see them as the rules of the game. Douglas North is one of the most famous supporters of this viewpoint.

North (1990: 3) defines institutions as *"the rules of the game in a society or, more formally, the humanly devised constraints that shape human interaction. In consequence they structure incentives in human exchange, whether political, social, or economic. Institutional change shapes the way societies evolve through time and hence is the key to understanding historical change."* He distinguishes between informal (sanctions, taboos, customs, traditions, and codes of conduct) and formal (constitutions, laws, property rights) institutions and their enforcement aspect.

North argues that there is a distinction between institutions (i.e., the rules of the game) and their actors (i.e., the game players, also called stakeholders within this research). He defines these actors as organisations, i.e. *"groups of individuals bound by a common purpose to achieve objectives"* (North, 1990). Actors may interpret the same institution with different meanings. Such differences can give rise to debate or conflict and lead to the incremental modification of those institutions over time (Jackson, 2010).

North's definition is assumed for this research. Other scholars take a similar perspective, such as Ménard und Shirley (2005: 1) who define institutions as "*the written and unwritten norms, rules and constraints that humans devise to reduce uncertainty and control the environment. These imply:*

i. *written rules and arrangements that govern contractual relations and corporate governance,*
ii. *constitutions, laws and rules that govern politics, government, finance and society*
iii. *and unwritten codes of conduct, norms of behaviour and beliefs."*

Groenewegen et al. (2010: 25) further distinguish between the formal and informal institutions: formal institutions are defined "*as public rules of behaviour that are designed by a public authority with legislative power (parliament or senate) and enforced by (i) a public authority with executive power (the administration or government, making use of police, regulatory agencies and other enforcement agencies); and (ii) a judiciary power (judges) that has the right and the power to penalize an individual or organisation for breaking the rule."* Informal institutions are defined *"as private rules of behaviour that have been developed gradually and spontaneously and do not need any legal enforcement because the rules are sanctioned by the private parties themselves or because it is in the self-interest of the actors to follow the rules of their own accord."*

Historically, institutions were first seen as having evolved in a way that assured they were always efficient; however, it became the view that societies that possess relatively efficient institutions are very lucky (Nelson and Sampat, 2001: 36).

In light of Sections 3.2 and 3.3, institutions are seen as a set of rules shaping the interaction between actors involved in the functioning of a technological systems (Koppenjan and Groenewegen, 2005), such as network industries.

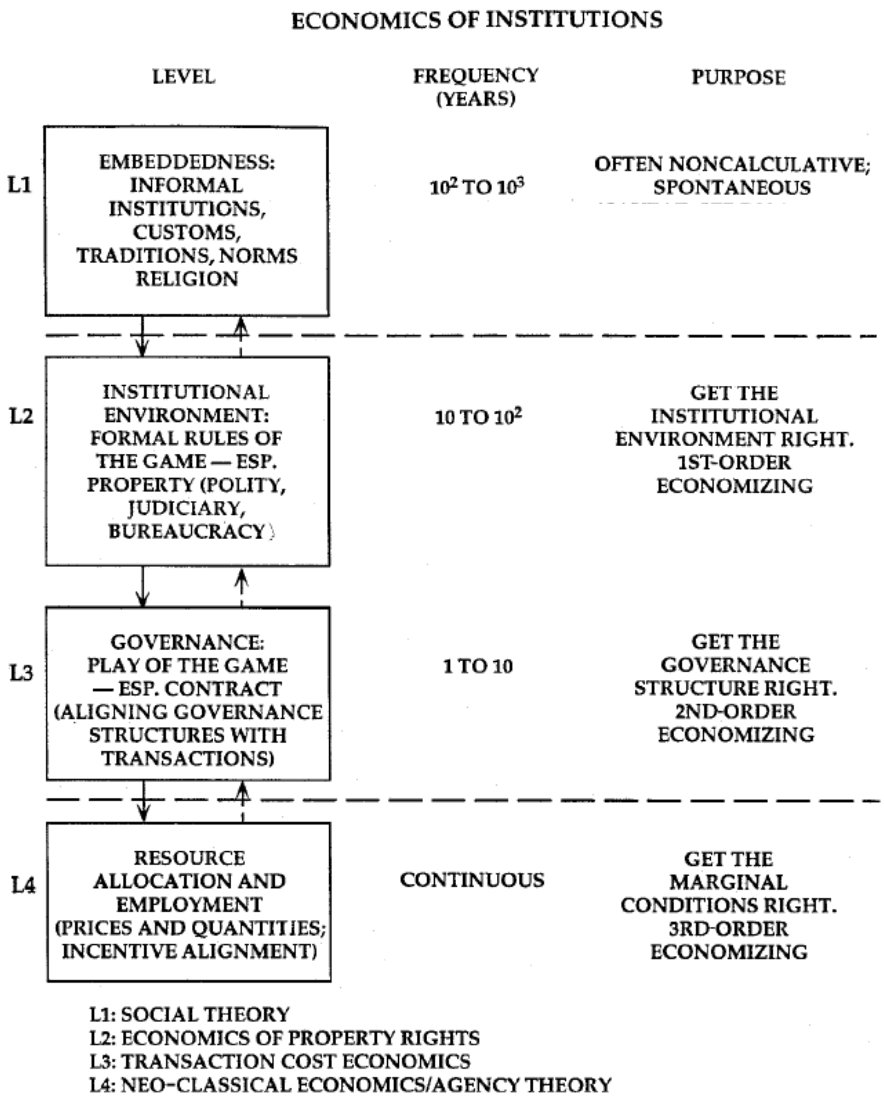
The chosen definition of institutions comes from scholars involved in New Institutional Economics (NIE) such as North. NIE is an interdisciplinary compilation of economics, law, organisational theory, political science, sociology, and anthropology to understand the institutions of social, political and commercial life (Klein, 2000). Its primary language is economics and its origins are in Original Institutional Economics (OIE). OIE departed from neoclassical economics in its recognition of the importance of institutions in structuring human behaviour and economic exchange (Ménard and Shirley, 2005). NIE aspires to explain why and how institutions emerge, function and evolve (Williamson, 2008). It is interested in social, economic and political institutions that govern daily life (Klein, 2000). It not only incorporates institutions in economic analysis, but considers policy making as well.

NIE builds on the assumption of scarcity and competition (Williamson, 2000). It differs from standards neoclassical: there is no perfect information, the rationality of actors is bounded and transactions are neither costless nor instantaneous. Actors have a bounded rationality because they lack complete knowledge for their decision making due to their cognitive limitations, time and information constraints (Williamson, 2000). Therefore, actors adopt an opportunistic behaviour based on their knowledge and due to the information asymmetries. Finally, NIE focuses on transactions costs and not production costs like classical economics. Transaction costs economics is one of the three pillars of NIE with the property rights theory and the agency theory[51] (Groenewegen, 2005: 7).

In Transaction Cost Economics (TCE), the transaction is the unit of analysis (Williamson, 2009). Transaction costs refer to the costs incurred when making an economic exchange. They consist of several aspects (Groenewegen, Spithoven et al., 2010: 22): 1. Search and information costs; 2. costs to draft, to negotiate and to conclude contracts; and 3. monitoring costs and enforcement costs. The costs under 1. and 2. are ex-ante costs, whereas under 3. they are ex-post costs. These costs cannot be ignored and have to be optimised as much as production costs. Today's complex world requires more contracts and thus TCE increased in significance (Groenewegen, Spithoven et al., 2010). Section 6.1 considers TCE.

Williamson developed a model for the economics of institutions (Williamson, 1998). It distinguishes four levels of analysis of institutions and is based on two main criteria: first, the level of analysis and second, the frequencies and purpose of change of institutions. Both of these criteria are qualitative and aim to highlight only some general differences.

[51] Agency theory concerns the relationship between a principal and an agent. An actor delegates to another some authority to act on his behalf. The reason behind is that an agent has a better information or expertise in a given field. This advantage causes the so called information asymmetry. Therefore, the key questions in agency problems are (i) how can a principal be sure that the agent acts according the task and authority delegated, and (ii) is it possible to define incentives in contract which ensure the principal that the agent will take the same actions as the principal would take. A large literature base has explored the influence of asymmetric information in regards to policy making (e.g. regulation) for natural monopolies such as the electricity sector (Fremeth and Holbrun, 2009).



Source: (Williamson, 1998: 26)

Figure 3-2: The four levels model of Williamson

Informal institutions are located at level 1. The formal ones at level 2. This level is mainly affected by property rights theory. By taking the rules (property) of the game introduced at level 2, level 3 addresses the play (contracts) of the game. The latter level concerns transaction costs economics. Finally, level 4 relates to agency theory which stresses at ex ante incentive alignment rather than ex post governance.

To enable comparative means, a similar model as the one of Williamson for institutions has been introduced for technologies by Künneke (see Table 3-1). Technological paradigms are long-term waves of technological practices (e.g. currently ICT and biotechnology). Technological trajectories are defined as the pattern of normal problem solving activity on the ground of a technological paradigm[52] (Dosi, 1982). According to Dosi, *"continuous changes are often related to progress along a technological trajectory defined by a technological paradigm, while discontinuities are associated with the emergence of a new paradigm*" (1982: 147). Trajectories lead towards more mechanisation and economies of scale (Nelson and Winter, 1982). According to Nelson and Sampat the notion of "routine" refers to "*a collection of procedures which, taken together, result in a predictable and*

[52] Dosi defines a "technological paradigm" as a definition of the "'relevant" problems and of the specific knowledge related to their solution (1982).

specifiable outcome" (2001, p. 42). The "routines" deal with the optimisation of scale and scope of a given technology. The last level of the model refers to the day-to-day management of systems components.

Table 3-1: The four levels model of Künneke

Level	Economics of technological paradigm	Frequency of change (years)	Purpose
1	Technological paradigm	> 100	Often non-calculative and spontaneous
2	Technological trajectory	10-100	First-order economising: development of coherent and efficient technological systems
3	Routines	1-10	Second-order economising: optimisation of individual technical components
4	Operation and management	Continuous	Actual operational management

Source: (Künneke, 2008: 244)

This research dealt mainly with levels 2 and 3 of both models. It relates therefore to property rights and transaction costs, as well as technological trajectories and routines.

3.2 Co-evolution between institutions and technologies in network industries

Co-evolution is the reciprocal interactions between two populations, entities or systems. These interactions have a significant causality linking them. The literature on co-evolution between institutions and technologies in the case of network industries describes the general process of changes within institutions and technologies and highlights the necessity to align these changes (Finger, Groenewegen et al., 2005). This Section develops co-evolution between institutions and technologies in general, followed by the case of network industries and focusing on the case of the electricity sector.

3.2.1 Co-evolution between institutions and technologies in general

The term "co-evolution" originally comes from biology. It relates to changes of an object triggered by the change of a related object. Biologists focus on a maximum of two entities co-evolving (Kallis, 2007). Thus, the literature on co-evolution used in this research focuses solely on the two entities of institutions and technologies.

Entities or systems co-evolve when they have a causal impact on each other's evolution (Murmann, 2003). Thus they depend upon each other and advance step by step through a co-evolutionary process. Furthermore, co-evolution as interactions between evolving systems has to be *"strong"* and in *"localized proximity"* (Winder, McIntosh et al., 2005: 353). The interactions may involve multiple causes at different spatial, temporal and organisational levels (Kallis, 2007). The system boundaries may remain fuzzy.

Changes in policies, organisational forms and different technologies have been analysed in co-evolutionary literature (Kallis, 2007). A co-evolutionary analysis can shed light on possible causes and explore *"types of circumstance and appropriate policy responses"* (Winder, McIntosh et al., 2005: 356). Whether a co-evolutionary process is beneficial for both entities depends on the particular causality linking them (uni- or bi-directional), which has to be specified in empirical analysis (Murmann, 2003: 22-23). Co-evolution can thus be described as a process, whereby there is nothing a priori good or bad with it.

Kallis (2007: 5) concludes on co-evolution that the *"goal is not to define precisely when it is co-evolution, and the go out and "find" it"*. It is to use co-evolution to try to make more sense of complex phenomena. Moreover, the research on co-evolution *"must be considered an intermediate step towards the understanding of the socio-economic system, or, at least of parts of it more closely related to the evolution of technology"* (Saviotti, 2005: 10).

Co-evolution between institutions and technologies remains a descriptive literature. Saviotti (2005) develops this co-evolution for example in regards to innovation. The literature describes well the general processes and highlights the necessity of aligning institutions to technological changes and vice versa. But the way to align the two is far from being fully understood and therefore calls for further research and explanation (von Tunzelmann, 2003).

Changes created by co-evolution are often path dependant which highlight historical lock-ins for example of technologies and institutions (Kallis, 2007). It can explain why it is so difficult to escape unsustainable configurations. Co-evolution however includes the continuous generation of changes and hence the omnipresence of alternatives and long-term opportunities to break through path-dependencies.

Furthermore, changes are triggered by radical and incremental innovation. Often referred as to technological innovation which leads to institutional changes, innovation can also occur on the institutional side and thus shape the further evolution of technologies.

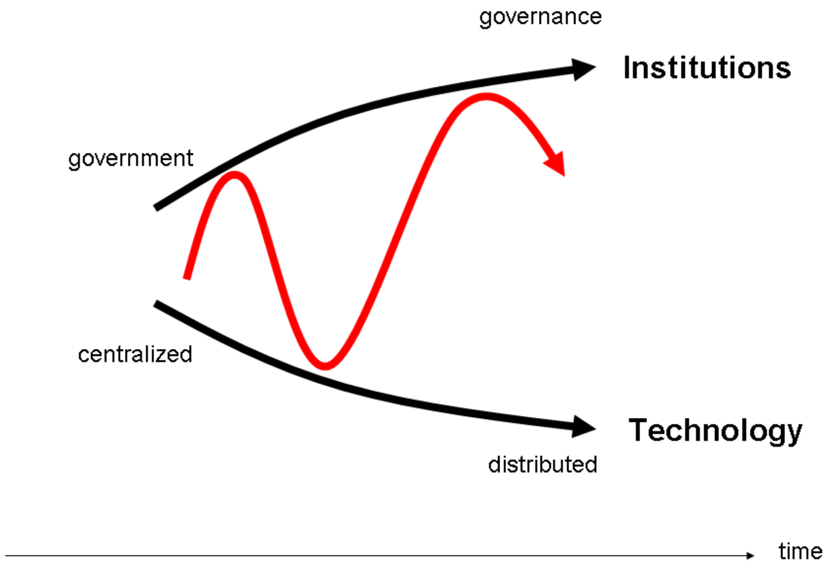
To be effective with new technologies, *"a nation requires a set of institutions compatible with and supportive of them. The ones suitable for an earlier set of fundamental technologies may be quite inappropriate for the new"* (Nelson, 1994: 58). The literature of co-evolution between institutions and technologies is not yet able to instruct policy makers how to ensure that a transition to new technologies will be accompanied by the emergence of a set of institutions that support its functioning (Scholten, 2009b), even though *"technological change and institutional change are the basic keys to societal and economic evolution"* (North, 1990: 103). This is partly due to the fact that the characteristics of the institutions appropriate to a particular technology are still unclear (Saviotti, 2005).

3.2.2 Co-evolution in network industries

Finger, Groenewegen and Künneke postulate that co-evolution can be observed in network industries because of the interactions between their institutions and technologies (Finger, Groenewegen et al., 2005; Künneke and Finger, 2007). For Weijnen and Bouwmans (2006), the co-evolution between institutions and technologies cannot be understood by just looking at the structure and dynamics of one of them. Both, technologies and institutions matter. Both are interconnected and interwoven in many ways. The interactions are complex, as well as the technological and institutional networks themselves. The performance of the network industries (see Section 3.3.1) is influenced by the co-evolution between their institutions and technologies.

Liberalisation for example, as an institutional process, leads to changes which occur within levels 2 and 3 of the four levels model of Williamson (see Figure 3-2). Within a co-evolutionary perspective, these institutional changes lead to technological changes which also occur on level 2 and 3 of the corresponding model of Künneke (see Table 3-1). Technologies in the case of network industries also evolved during the past decades and cannot be taken as constant. For example, ICT changed the telecom sector, as well as other sectors. ICT is an important enabler for the liberalisation in the electricity sector (Lehtonen and Nye, 2009), which highlights co-evolution. It improved among others the control opportunities available to systems engineers (Nightingale, Brady et al., 2003). The literature on co-evolution in network industries does not provide a framework to measure the impact of the changes nor to measure and compare institutions and technologies.

Network industries typically developed from vertically integrated technologies, governed by a national monopoly, state owned and centralized, towards more unbundled and distributed technologies, governed by a combination of market, regulation and government intervention. These evolutions have a bi-directional influence. Figure 3-3 illustrates the co-evolution graphically. In other words, formal centralised authority has been dispersed both up to supranational institutions and down to regional and local authorities (Hooghe and Marks, 2010). According to Hooghe et al., an index of regional authority in 42 democracies and semi-democracies reveals that 29 countries have regionalised and only two have become more centralised since 1950 (Hooghe, Marks et al., 2010). During the last two decades, new supranational authorities were set up and public/private networks of diverse kinds have multiplied from the local to the international level (Hooghe and Marks, 2010).



Source: (Finger, Laperrouza et al., 2010: 3)

Figure 3-3: The co-evolution between institutions and technologies in the case of network industries

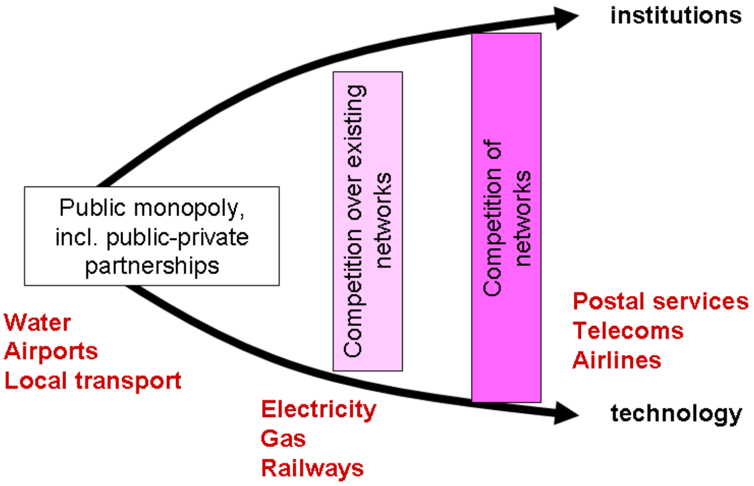
There is no institutional determinism leading to a particular set of technological routines or trajectories, and vice versa, no technological determinism leading to a particular set of institutions. Institutional and technological designs appear to be established through a process of incremental steps and with interaction between the involved actors (Koppenjan and Groenewegen, 2005).

Finger et al. (2010) illustrate the three major configurations in network industries using the same figure as above (see Figure 3-4). These configurations cannot be seen as permanent, but only temporary (De Brucker, Macharis et al., 2011). The first configuration is the public monopoly which is owned by the public sector and managed either by a public entity (administration or enterprise) or a private operator (in so-called public-private partnerships (PPPs)). This configuration characterises the network industries before liberalisation and is still prevalent in the water (distribution and sewerage) and local/regional transport sectors, as well as for airports.

The second configuration is the unbundled network industries following the liberalisation process. The competition is for the market, i.e. for access to existing networks. The network industry is regulated by sector-specific and independent regulatory authorities. The monopolistic network is owned and managed by either a public or private entity. Examples are the liberalised electricity, gas, air transport, and sometimes railway sectors.

Finally, the third configuration is the unbundled network industry with competition of networks. The network industry becomes much more fragmented and several networks can be loosely tied together. Sector-specific regulation may be replaced by solely competition regulation. The telecommunication and postal sectors, as well as airlines, are examples.

Today, network industries can lack overall planning and control of the whole infrastructure. Instead, various actors exercise control over selected part of the infrastructure. Such "distributed" planning and control may result in worsening the performance of the network industries (depending on how performance is defined – see Section 3.3.2).



Source: (Finger, Laperrouza et al., 2010: 6)

Figure 3-4: The three main configurations in network industries

The shift from one set of configuration to another (the trend being towards more distributed technologies and multi-level governance) is triggered by institutional and technological changes. On the institutional side, it is as developed above mainly the liberalisation process. On the technological side, it is mainly innovation in ICT which offers new opportunities for the network industries thus making them evolve. Coordination can happen in a more distributed and horizontal way compared to the former vertical integrated and centralised infrastructure. However, certain network industries may never develop into markets or even move back to monopolies (reversing the arrows in Figure 3-4). The evolution between configurations can also be due to incoherence in the case that technologies fit with one set (e.g., monopoly), whereas institutions fit with another one (e.g., competition over networks). Technologies or institutions will have to evolve in one direction or the other.

The case of electricity as a network industry affected by co-evolution between institutions and technologies is described into more details below.

3.2.3 The case of electricity

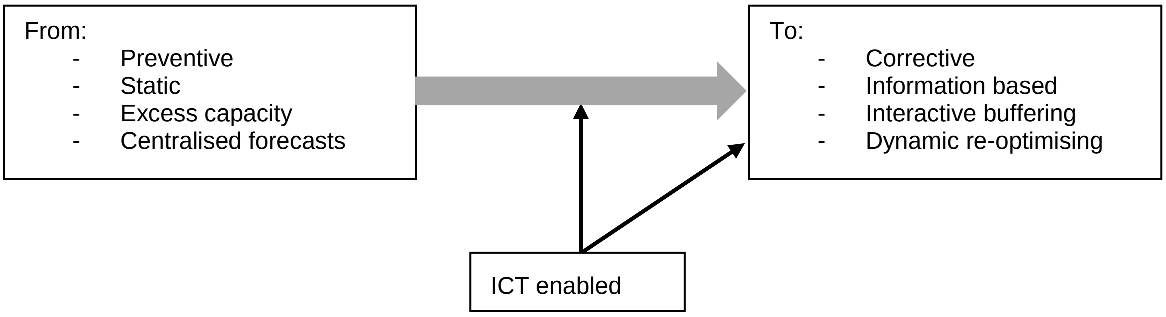
The main characteristic of the electricity network is that supply and demand of electricity have to be balanced in real-time in order to avoid any disruptions of the network. Electricity flows according to Kirchhoff's physical law and, in general, cannot be directed between specific actors within a grid simply based on contractual rules. The continuous delivery has to be guaranteed within specific quality standards (e.g., voltage, frequency and reliability) and leads to significant transaction costs, especially in a liberalised market. These technical specificities affect the design of institutions such as the market rules and the regulation. The appropriateness of the institutions in place may change as a result of technological change.

Historically, the electricity sector started with stand-alone grids and distributed generation, before becoming national connected grids and enabling significant economies of scale. The sector became strongly vertically integrated between production, high-voltage long-distance transmission, low-voltage distribution, and end use. A single firm could integrate all activities within its own scope of control, which was typically organised as a regional monopoly. Generation, and later transmission, could also be integrated, whilst distribution and sales belonged to another firm. The institutional constructs of the electricity sector were largely within the technical system boundaries of the respective networks. With the liberalisation in the 1990s, this changed quite fundamentally. Joskow's work on the introduction of competition into regulated network industries showed the path from hierarchies to market in electricity (Joskow, 1996). From an institutional perspective, liberalisation required the unbundling of major parts of the value chain into independent entities. The transmission and distribution networks are considered as natural monopolies, thus cannot easily be opened to competitive markets. Therefore, they were organised as monopolies which are subjected to sector specific regulation; whereas the generation, trade, metering and sales are considered as commercial activities that can be performed under market conditions. Overall, the electricity sector has developed from a utility into a commodity, from a nationally oriented industry into a global business, and from dominant political involvement to a market driven activity (Künneke and Finger, 2007). Electricity pricing is thus now driven by market prices whereas before, prices were mainly based on long-term contracts. Investments were driven by long-term planning based on future consumption assessments. The liberalisation investments are now demand-side driven by price signals. The liberalisation process favours the development of distributed and small scale power production, which requires less investment and is perceived as being less risky (Künneke, 2008). Furthermore, the governmental facilitation of RETs also leads to more distributed generation. However, with the unbundling and with distributed investment decisions, the market is unable to ensure long-term coordination to guarantee an adequate level of peak capacity which corresponds to the quality requirements of the consumers (e.g., reliability and affordability), as the vertically integrated industry was able to do (Finon and Pignon, 2008).

One of the latest developments in the electricity sector involving technological and institutional aspects is the development of so-called "smart grids"[53]. Smart grids contribute to the integration of the intermittent RETs. They are partly facilitated by institutional measures (e.g., research and development grants). Electricity networks use ICT to monitor and efficiently manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. They shift the electricity network from a centralised, large scale, supply dominated system towards a more decentralised, flexible, responsive system with bi-directional electric energy flows. ICT enables this shift as shown in Figure 3-5. The future electricity network might function similarly to the internet, i.e. networks with a certain level of independency interaction in a connected way. The electricity web is an interesting alternative technological paradigm and quite different to the current network (Künneke, 2008).

[53] There are various definitions for smart grids including micro-grids mentioned in Table 2-1. The European Smart Grid Task Force defines Smart Grids as electricity networks that can efficiently integrate the behaviour and actions of all users connected to it — generators, consumers and those that do both — in order to ensure an economically efficient, sustainable power system with low losses and high quality and security of supply and safety.

http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/expert_group1.pdf (accessed on 27.02.2012)



Source: (Ilic and Jelink, 2009: 158)

Figure 3-5: The enabling role of ICT in electricity

The historical trend to move the operation of the electricity grid up from the local to at least the national level could become reversed. The "smartening" of the electricity network is an evolutionary process which involves automation (e.g. refrigerator on hold when peak demand), access to information (e.g., consumption of devices, price signals) and the transfer of control of certain devices from consumers to utilities or grid operators. Consumers are encouraged to become directly involved in their energy usage and management. Smart grids could contribute to the safeguarding of the system relevant functions of the electricity sector (see Section 3.3.1). However, there are legal questions (e.g. data protection) and cyber security issues to handle. Furthermore, significant investments are required to record the data of consumption profiles over time and real-time consumption of every relevant point in the network.

The smart grid development may affect, in a co-evolutionary way, the institutions shaping the unbundling. On one hand, smart grids might require stronger unbundling to avoid discrimination potential; on the other hand, unbundling can also hamper the development of smart grids (Friedrichsen, 2011).

Beside the convergence with the ICT sector, further convergence is happening in the electricity sector. Firstly there is convergence of the gas and electricity sector especially in countries, where combined heat and power plants are used in a distributed way for heat and electricity generation (e.g., Netherlands, Switzerland). Secondly, the railway sector generates its own electricity (e.g., in Switzerland), but to optimise capacity utilisation and following the liberalisation, electricity networks of the railway sector and electricity sector could be combined. This can require adaptation to ensure interoperability (e.g., frequency alignment).

Overall, following the liberalisation process, performance improvements have been observed in several countries, especially where the performance of the state-owned monopolies was particularly poor. However, the setting up of well-functioning competitive markets for electricity is very challenging, both technically and institutionally (Joskow, 2008). Furthermore, with the liberalisation leading to more complex networks and with the lack of investment, in particular in new transmission facilities, the electricity network is being operated much closer to its limits and cascading outages are more likely to happen (IRGC, 2007).

To sum up, co-evolution can be used as a perspective to look at changes within institutions and technologies which have an interactive effect on each other. Co-evolution does not lead to any recommendation on the way changes have to be aligned, neither how policy can shape further development.

3.3 The coherence framework

Based on the previous Section on co-evolution and to remedy the identified gap of how to align institutions and technologies, the coherence framework has been developed. This framework is the main theoretical framework used in this research.

The initial coherence framework aimed to evaluate the degree of coherence between institutions and technologies in network industries thus leading to an evaluation of the performance of such industries. As developed by Künneke, Finger, Groenewegen and Menard, it contains a way to compare and match institutions to technologies (Finger, Groenewegen et al., 2005; Groenewegen, 2005; Künneke and Finger, 2007b; Künneke, 2008; Künneke, Groenewegen et al., 2010; Ménard, 2009). However, the framework remained very conceptual and qualitative. Furthermore, it offered only a static analysis. The framework was therefore developed further, including within this research.

The framework remains conditioned by the fact that it applies to network industries or technical systems and not to individual products so often described in the literature of co-evolution. The literature on the coherence framework highlights the need of coherence between institutions and technologies and thus the need of alignment when changes are made to the network industry. It does not yet provide a roadmap of implementation of changes, but should contribute to formulate policy recommendations.

This Section introduces the initial framework followed by its latest development.

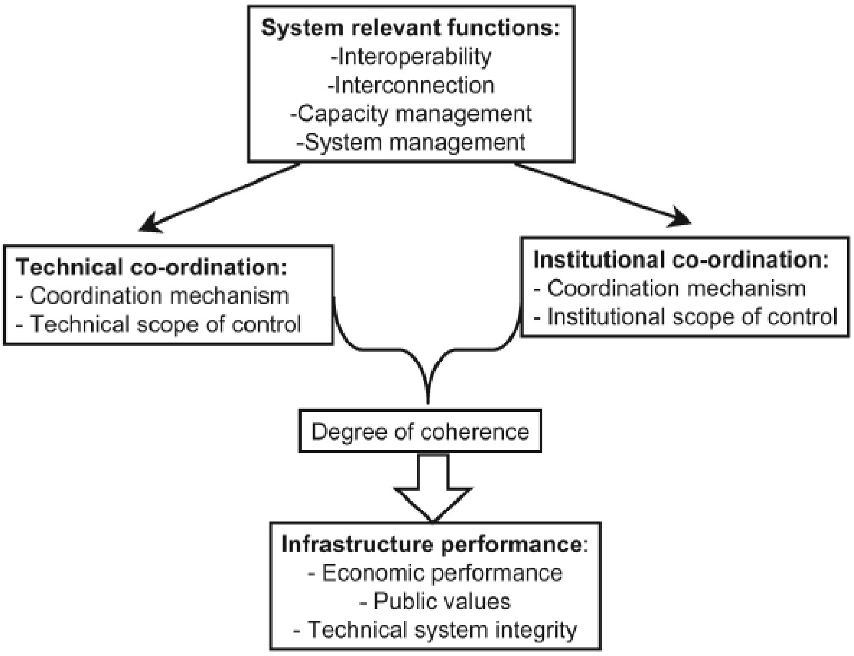
3.3.1 The initial framework and literature review

Before describing the initial framework, the literature is firstly reviewed. The reference paper in the coherence literature was written by Finger et al. (2005) and introduced the framework. The main components are detailed below. Other papers continued to develop some aspects of the coherence framework and are mentioned in Appendix E. This Appendix also summarises the latest working and conference papers which influenced the further development of the framework (see Section 3.3.2). This includes work on the characteristics of network industries, on the dynamics and the role of actors, and on performance.

Most papers, which relate to the framework and analyse network industries, have been written following the liberalisation. They use the coherence definition of the initial paper (see below). The literature review clearly shows the need for coherence between institutions and technologies within the co-evolution in network industries. There is a necessity to align technologies and institutions in order to safeguard reliability and assure sustainability (Künneke and Finger, 2007). The identification of possible incoherence allows for a better understanding of required changes (Künneke, 2008). Furthermore, the coherence between institutions and technologies is linked with the performance of the network industries.

Some specific cases, such as hydrogen (Scholten, 2009a), mini hydropower (Crettenand, 2009), pumped-storage small hydropower (Crettenand, 2011a), ports (Asquer, 2011) and smart grids (Bolton and Foxon, 2010), have been studied in a first attempt.

The initial framework in its static view is represented in Figure 3-6. Taking into account the system relevant functions (interoperability, interconnection, capacity management and system management), the degree of coherence between technology and institutions increases with the alignment of their scope of control and coordination mechanisms. The degree of coherence influences the performance of the network industry (referred to as “infrastructure” in the Figure) as further elaborated below.



Source: (Finger, Groenewegen et al., 2005: 239)

Figure 3-6: The initial framework of coherence between institutions and technologies

The system relevant functions are crucial to the functioning of network industries which are complex infrastructures. If these four functions are not properly assumed, then the functioning of the infrastructure system is diminished. These functions are always assumed by way of a combination between technologies and institutions and can be described as follows (Finger, Groenewegen et al., 2005): First, there is the function of interconnection, which deals with the physical linkage of different networks that perform similar or complementary tasks. Interconnecting networks is the prerequisite for operating them as a system or running a common market on them. Second, interoperability ensures that mutual interactions between network elements can take place. In an electricity network, this is achieved either by synchronizing the network elements to the same alternating current frequency (e.g., in Europe, 50 Hz), or by linking them through a direct current interconnector to transform the electricity at both ends of the interconnector. In the railway networks, different historical track gauges are either harmonized or rolling-stock is fitted with flexible gauge axles. Third, capacity management deals with the allocation of scarce resources within the network. To stay with the railway sector, the allocation of slots relates to capacity management. Usually, there are several levels of capacity management. On the strategic level the access to the network is the bargain. On the tactical level lays the governance of the slots. Finally, the operational level deals with the real-time capacity management reacting to any unforeseen event. Fourth, system management relates to the question of how the overall system is being managed (except capacity management), as well as how the quality of service is safeguarded. It deals also with the coordination of the physical and informational flows across the network. From an economic perspective, the technical system management is a pure collective good that cannot be provided by market allocation (Künneke, 2008), thus has to remain under public authority. System management relates also to the controllability and storability of the flows within the network (see also Section 3.3.2). For example, airplanes can be deviated to a certain extent, as well as trains, but electricity much less. Airplanes can be kept a certain while in the air, trains can be stored on the railway tracks, whereas electric energy cannot be stored but only transformed in another energy form to be retransformed back afterwards.

In the literature, critical technical functions also refer to these system relevant functions. It is important to underline that the well-functioning of the infrastructure does not relate only to the technological side, but the institutional as well. Künneke and Finger (2007) developed in more detail the critical technical and institutional functions, i.e. system relevant functions, with in mind the four level models of Williamson and Künneke (see Figure 3-2 and Table 3-1).

The degree of coherence between institutions and technologies was initially defined by the coherence in scope of control (i.e., geographical scope) and the coherence between coordination mechanisms (decentralised, centralised, peer-to-peer). The coherence in scope of control is given if the institutional and technological scope matches, i.e. have comparable system boundaries. In an idealistic case, both scopes would overlap perfectly, which is almost never the case in network industries. In the most favourable cases, one scope will integrate the other (see representation a. in Figure 3-7) thus guaranteeing a full coherence in scope in one case (the circle integrates the full rectangle), whereas the other way round it is not totally the case. However, in most of the cases, the institutional and technological scope of control overlap more in the way of the representation b. in Figure 3-7, thus leading to incoherence. An example is the electrical grid where the technological scope of control in Europe is the UCTE network, whereas the institutional scope of control is given by the national states and may even overlap in certain cases (e.g., power trading).

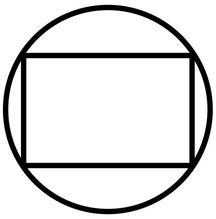
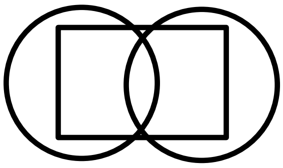
a.  b. 

Figure 3-7: Coherence in scope of control
Do the institutional (circles) and technological (rectangle) scopes match

The coherence between coordination mechanisms is based on the distinction between the levels of decision-making (see Table 3-2). The centralised system is based on a top-down approach *"in which some centralised authority controls all major systems elements or operations"* (Finger, Groenewegen et al., 2005: 242). The electricity sector before unbundling was organised this way. The decentralised system is based on a bottom-up approach in which decision-making is distributed among numerous actors. Coordination is realised by certain institutional arrangements (e.g., competitive markets), but without any active planning or direct intervention. The road sector is an example where actors decide in a distributed way how they use the infrastructure which is governed by certain regulations (e.g., road pricing). Finally, in the peer-to-peer coordination, actors mutually coordinate their activities based on bilateral agreements. An example is the air traffic sector where alliances of air carriers mutually coordinate their services to gain competitive advantages, which often include a bilateral technical coordination as well. From the coherence perspective, technologies and institutions should have the same coordination mechanism. But where the institutional coordination of networks has become unbundled, as well as market oriented and guided by private sector values, the technological coordination may have remained to a large extent centralised, top-down organised and guided by public values. Technological coordination is essential for safeguarding the functioning of the infrastructure, while in liberalised markets the economic activities are forced to be operated independently from each other. Therefore, there seems to be a tension between the technological and institutional requirements for the coordination.

Table 3-2: Coherence in coordination mechanisms

Coordination mechanism	Technical coordination	Institutional coordination
Centralised	Centralised control: top-down	Planned economy
Decentralised	Distributed control bottom-up	Market economy; classical contracting
Peer to peer	Peer-to-peer control	Relational contracting

Source: (Finger, Groenewegen et al., 2005: 243)

In the later stages, two more perspectives of coherence were added, the coherence in territorial resolution (i.e., how detailed the geographical view is) and the coherence between the speed of adjustment (e.g., operational balancing, duration of contracts and lifetime of infrastructures). The coherence in territorial resolution was initially introduced by Duthaler et al. (2010) and is related to the coherence of scope of control. It concerns the level of detail (e.g., granulometry) and the structure of the perspective on the scope of control. An example in the electricity sector is the question of if one looks just at the high voltage grid or one includes the lower voltage network as well. Both are not influenced by the same institutional settings. Therefore, the technological and institutional view of the scope of control has to be based on the same level of detail to ensure coherence in territorial resolution.

Finally, the coherence between speed of adjustment comes from Künneke et al. (2008: 17). It relates to the time frame for technological and institutional decision-making, which must also be coherent. The capacity allocation is one example for which institutions should react in the same time period as the technology does, and vice versa. An example is the technological reaction time of trains to institutional arrangements, i.e. change in signalling. In electricity, switching times need to be coherent between the technological feasibility and the institutional settings. Lastly, the lifetime of technology in the case of network industries can be several decades (e.g., lifetime of power plants, transmission lines, railways tracks, etc.). Therefore, the institutions related to these technologies should ideally have the same lifetime. If not, which is generally the case, the institutional change will lead to a technological change thus lead to co-evolution.

To sum up, the degree of coherence increases the better institutions and technologies are aligned. Its influence on the performance in the network industries is sector-specific and time-dependent (Duthaler and Finger, 2010). Apart from coherence, other technological and institutional factors contribute to explaining performance (see below).

Performance in the framework was defined by way of three parameters: the economic performance, the public value and the integrity of the technical system as shown in the next table. The economic performance concerns the static, dynamic and system efficiency. The public value is defined by the quality, accessibility, affordability and reliability of the service, as well as the environmental aspects. Performance criteria of the technical system integrity include resilience and robustness. Some of these parameters can conflict with each other such as static efficiency and consumer protection with social or technical parameters (security of supply, universal service quality, robustness, etc.).

Table 3-3: Definition of performance according to Finger et al.

Economic performance	Public value	Technical system integrity
Static efficiency**: Price efficiency: prices equal marginal costs**	**Services of consumer interests**: Universal Service: quality, accessibility, affordability, reliability	**Resilience or robustness**: Capacity of a system that is in some kind of distress, to resist or adapt to this situation in order to maintain an acceptable level of performance.
Static efficiency**: Allocation efficiency: all customers are served that are prepared to pay at least the market price**	**Services of general (collective) interest**: Security of supply, national security, social protection, environment	
Dynamic efficiency**: Refers to the capacity of the system to innovate from a systemic perspective and to the benefit of the overall system**		
System efficiency**: Refers to the overall (systemic) efficiency of the industry, throughout all activities in the value chain**		

Source: Adapted from (Finger, Groenewegen et al., 2005, Ch. 2.3)

There are several weaknesses in the initial framework. Some of them have been raised and discussed since the first paper on the coherence framework (Crettenand, Laperrouza et al., 2010; Finger, Laperrouza et al., 2010). The next Section elaborates on the most important weaknesses and describes the current state of the framework.

3.3.2 Current state of the framework and further research

The definitions of coherence and performance are among the weaknesses of the initial framework (Crettenand, Laperrouza et al., 2010). The definition of coherence between institutions and technologies remains “fuzzy” and should be clarified. In addition, the term "coherence" is often equal to "alignment" in the literature, thus creating confusion between both terms. The new presentation of the framework (see Figure 3-9) replaces "coherence" by "alignment" as argued below. The definition of performance in network industries also remains unclear as shown below.

Furthermore, the causality between coherence and performance must be developed and defined once the latter two are more defined. Future research will show if more coherence always increases the performance or not, and to which degree incoherence is required to trigger technological and/or institutional innovation.

The initial static framework was made dynamic in its presentation by adding a time arrow (see Figure 3-9). The dynamics, as part of the co-evolution between the institutions and technologies, are created by the actors as developed below and affected by the configuration in which a network industry can operate (see Figure 3-4).

Finally, the definition of the unit of analysis had to be further investigated. The initial development of the spatial and temporal scope of the unit was not clear. In the meantime, the unit of analysis has been defined as the geographical scope for which the performance between institutions and technologies is evaluated. For example, if the performance between institutions and technologies is evaluated for Switzerland, the geographical scope is provided by the national borders. Instead of choosing a political entity, the technical borders of a network industry can also be taken as unit of analysis (e.g., interconnected electricity network in a region of the World, e.g. UCTE). The temporal unit of analysis can either be given as a precise date or period (e.g., 2005-2010) in the past, or in the future. Furthermore, the detail of analysis has to be defined, i.e. if the whole network industry is evaluated or only a part of it (e.g., the railway track network, electricity transmission).

The coherence framework can also be illustrated as in Figure 3-8 with the typical engineering approach – the systemic view. There is a border of the system given by the choice of the unit of analysis. The components of the system interact and coherence is used as a lens to look at performance.

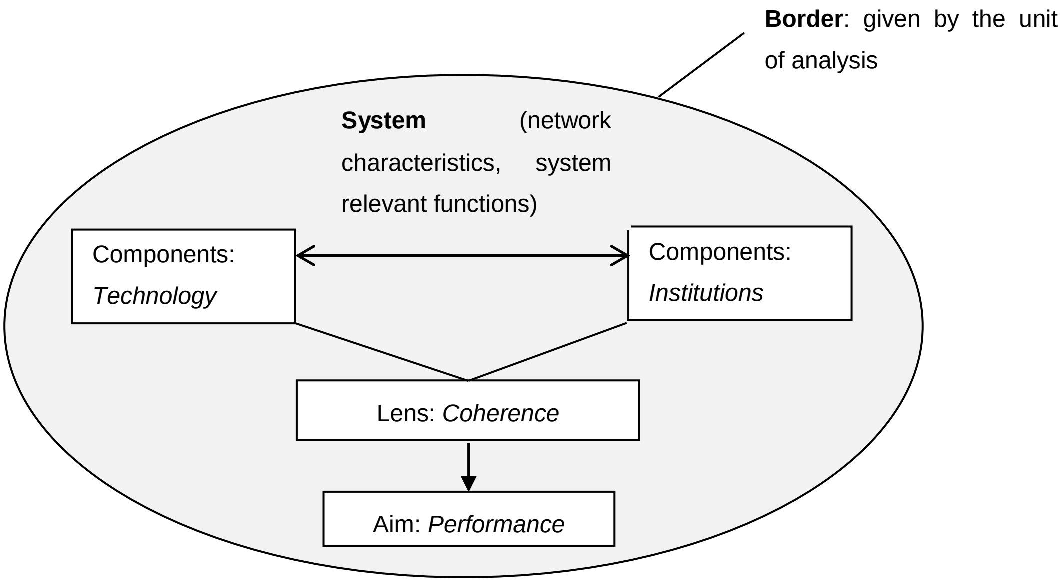


Figure 3-8: Systemic view of the coherence framework

The initial framework looked at institutions and technologies first, followed by the evaluation of the coherence and performance. Meanwhile, the focus has been set on performance because it is this ultimate outcome that matters for the society. Performance is not the result within the analysis, but is the starting point. Performance has thus to be defined first. Then institutions and technologies have to be aligned accordingly in order to reach the defined performance. Once the network industry is in place and operated, the performance should be measurable and therefore comparable with the initially defined performance.

In a broad sense, performance can be defined as the *"accomplishment of a given task measured against present standards of accuracy, completeness, cost, and speed"*[54]. In network industries, there is no consensus on the definition of performance (Karlsson, 2007: 2). This is partly due to unresolved problems in how to measure performance of network industries. Each network industry has its specific technological and institutional features which need to be taken into account, but there are similarities across the network industries as well.

A substantial body of literature on performance in network industries has developed since the late 1970s. The first attempts at evaluating this performance were associated with the failed attempts at large scale strategic planning in the 1970s (Boland and Fowler, 2000). Since then, several authors have been developing different approaches to performance (Lawrence, Houghton et al., 1997; Commission for the European Communities, 2004; Estache and Goicoechea, 2005; Jamasb, Mota et al., 2005; Martin, Roma et al., 2005). Several authors deal with regulatory performance, governance and performance, and ownership and performance (Boardman and Vining, 1989; Stern and Holder, 1999; Knieps, 2004; Spiller and Tommasi, 2005; Andres, Guasch et al., 2008; Gasmi, Noumba Um et al., 2009). These papers look at the regulation, industry structure, governance, ownership and then analyse the performance.

[54] http://www.businessdictionary.com/definition/performance.html (Nov 2009)

Ultimately, the key question is who is setting the performance definition within the network industry. For network industries, the consumers still perceive it as an essential service which is provided (not applicable for air transport). Thus, they will influence through their voting power (especially in Switzerland with the system of direct democracy) the government and its public policy objectives. Therefore, the key actor defining the performance in a network industry remains currently the government (Finger, Crettenand et al., 2011). Nevertheless, it is under lobbying and interest of all actors, i.e. stakeholders (e.g., operators, infrastructure managers, environmental organisations, regulators, consumer protection organisations, etc.).

Furthermore, the way performance is defined also depends if one has a sector perspective or a more narrow perspective such as for example the one of the infrastructure manager. The detail of perspective has significant implications particularly in network industries where downstream activities are, by definition, dependent on upstream activities.

The focus of many studies on a single category of performance fails to achieve comparative evaluation along several dimensions (Ménard and Ghertman, 2009: 170). Because the above mentioned institutional changes involve economic, social and environmental aspects, as well as technological ones, and because it is possible that there are trade-offs between these different aspects, studies need to use multiple categories.

The performance categories from Finger et al. (2005) take into account the multiple categories. Meanwhile, they have been developed further. The initial economic and technical performances are kept, the public value is divided in social and environmental performance, and the operational dimension is added. The categories have to be so large that they can be declined in every sector. Ultimately, the choice and weight of each category is a choice done by the actors.

The categories can be described as follows (Crettenand, Laperrouza et al., 2010) (omegalogical order):

- **Technical**: availability, physical losses, delivered service per capita
- **Social**: consumer satisfaction, accessibility, affordability, quality of service, safeguarding privacy
- **Operational**: reliability/safety, use of the network, congestion, punctuality
- **Environmental**: GHG emissions per delivered service, noise
- **Economic**: price evolution in the sector, subsidies, production costs, productivity

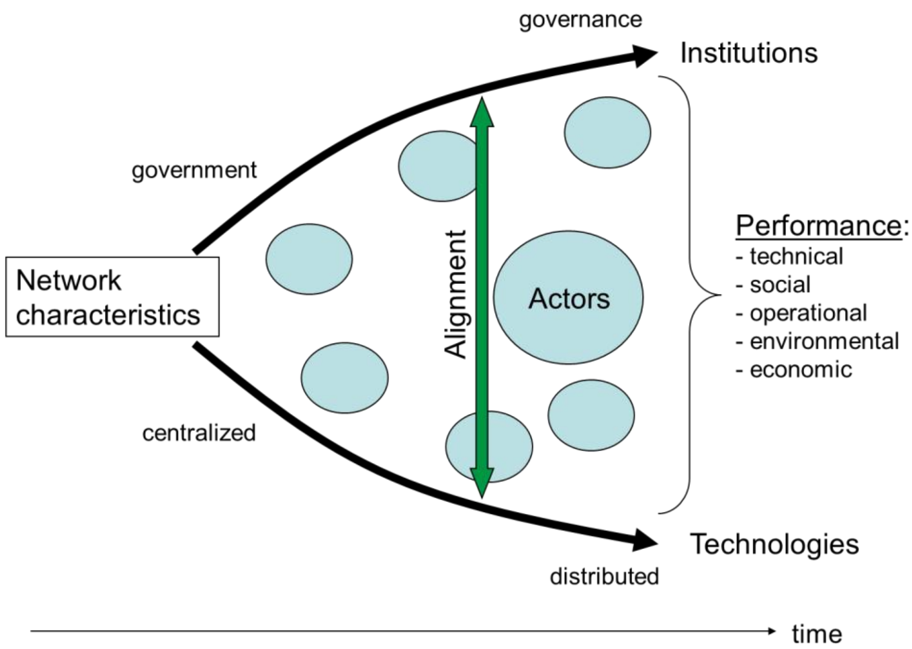
The different performance categories using adequate indicators can be used to monitor the performance in network industries. A given industry can be benchmarked with others of the same sector and regulation can set up the adequate incentives to reach the defined performance objectives.

The importance of the economic performance (mainly costs and productivity) is steadily increasing as a consequence of the institutional changes of the liberalisation and privatisation (Crettenand, Laperrouza et al., 2010). Even state-owned firms tend to be increasingly treated as private firms. Operational performance (mainly concerning security/safety) gains in weight too as acceptance of risk is falling. Furthermore, the environmental performance gains in importance and is mainly linked to pollution (e.g., GHG, noise). As the economic performance becomes the dominant part of the overall performance, the question in the end is how much the customers are ready to pay for which type of performance.

In the initial framework, performance was illustrated as a consequence of the degree of coherence. However, this only partially explains performance. Performance is not only the result of coherence, but is also a function of the institutions and technologies in place and their interaction, as well as influenced by the actors. Actors not only define the performance along with its categories at a given moment in time, but they also monitor the performance and should take adequate measures to keep institutions and technologies aligned over time in order to reach the defined performance.

New presentation of the framework

A new presentation of the framework was introduced by Finger et al. (2011) as shown in Figure 3-9. It incorporates the scheme of co-evolution in Section 3.2.2. The dynamics observed in most network industries, both from the institutional and technological perspective, were included. The institutions moved from being mainly created by governments (nationally centralised institutions, monopolies) to different modes of governance at several levels (e.g., local, regional, national, supra-national, global), thus leading to multi-level governance. Technology moved from centralised and vertically integrated to more distributed and unbundled technology, as it can for example be observed in electricity. However, the dynamics do not necessarily lead to continual unbundling and multi-level governance. The time arrow could be reversible in same cases as mentioned in Section 3.2.2.



Source: Adapted from (Finger, Crettenand et al., 2011)

Figure 3-9: The new presentation of the framework

Network characteristics refer to the technical specificities of network industries as mentioned in Section 2.1. In the framework of Figure 3-9, the network characteristics replace the system relevant functions of Figure 3-6. The functions are incorporated in the evaluation of the coherence, i.e. the alignment between the institutions and the technologies as developed below.

The network characteristics determine the way network industries operate and within this framework include the network topology, the capacity constraints and the flow types. Firstly, the network topology describes the vertical and horizontal set up of the network industry. In the case of electricity, the horizontal topology is given by the connections of networks of the same voltage level, whereas the vertical topology is given by the connections between networks of different voltage level.

Secondly, the capacity constraint relates to the fact that each network industry has a limited capacity. In the case of railways, there is a limited number of trains that can be operated between two points of a network within a given time period. In the electricity networks, the capacity constraint is given by physical laws. The growing amount of intermittent electricity production, mainly due to wind power, increases cross-border flows which enhances the significance of the capacity constraint. Such developments lead to co-evolution, such as institutional changes (e.g., more coordination rules) and technological changes (e.g., phase shifters (Jonker, 2010: 95)).

Finally, the flow types relate to the good that flows through the network. The flows are either continuous and indivisible (e.g., electricity), or come as packages (e.g., trains, airplanes). In both cases, there are technological limitations and constraints regarding the storability, controllability and transformability of the flows. In the electricity sector, the flow cannot be stored and the controllability is given by physical laws. The flows can be transformed between various voltage levels. In the railway sector, the trains can be stored (but within a limited time on tracks) and are controllable with institutions. Their transformability depends for example on the tracks and gauges, e.g. if an international train can be operated as a local train.

Taking into account the network characteristics, the institutions and technologies have to be aligned in order to reach the defined performance. The alignment, previously called coherence, can be evaluated with the four perspectives of scope of control, territorial resolution, coordination mechanisms and speeds of adjustment (see Section 3.3.1). The alignment can be evaluated along the five performance categories.

An important part of the alignment is given by the way the critical system relevant functions (CSRF) are ensured by the institutions and technologies (interconnection, interoperability, capacity management, system management). The CSRF, formerly system relevant functions, enable the functioning of the network industry based on its network characteristics. The term “critical” was added in order to stress the criticality of these functions (Finger, Crettenand et al., 2011). Interconnection and interoperability relate to a physical perspective of network industries (“hardware”), whereas capacity and system management relates to a management perspective (“software”). Not all functions have the same maturity within a network industry. Without safeguarding these functions, from a technological, institutional and alignment perspective, the network industries do not deliver their services with the defined performance.

The alignment matters not only between institutions and technologies, but within institutions and technologies as well. Institutions can be sub-divided between different levels such as global, continental, national and local. The various institutions have to be aligned and coordinated among themselves. The same accounts for technologies.

The definition and application of alignment still remains very qualitative and abstract. It has thus to be further elaborated and, if possible, made more concrete and quantitative. A possible avenue could be to introduce measurable indicators for the technologies and institutions for each of the four perspectives of alignment related to the functions, thus allowing a quantitative comparison of institutions and technologies.

Furthermore, the causality between performance and alignment has to be further developed. The work on the characteristics, functions and alignment should enable the comparison and matching of institutions and technologies (comparative alignment). From there on, recommendations for decision makers on how to facilitate such alignments will become possible (design alignment).

The actors within the framework can be grouped into three categories (Finger, Laperrouza et al., 2010). Firstly, certain actors are capable to shape the institutions under which all other actors, including themselves, behave. They are called institutional actors and are political actors, public administrators, and regulators. Political actors and public administrators are found at the local, regional, national and sometimes at the supra-national or even global level. Regulators in turn are mainly at the national and supra-national levels. *“The relationships between these three types of institutional actors are complex, with the political actors having the ability, at least to a certain extent, to define the basic rules. However, regulators and public administrators – especially at the supra-national levels – also have a considerable potential to define rules. Institutional actors basically respond to incentives that relate to discretionary power and less to reputation or money.”* (Finger, Laperrouza et al., 2010: 10)

Secondly, on the technological side, actors have the capabilities to innovate and develop technologies. By doing so, they force the other actors to react. Technological actors are found whenever innovation can be generated, such as within firms with R&D, universities and research labs. They may collaborate, compete or co-opete together. They operate within a given institutional framework.

A third category of actors are market actors who emerge with the creation of markets within liberalised network industries. Market actors provide the service of the given network industry. There are the incumbents, i.e. to former public administration or enterprise, and the new entrants. The incumbents have often been privatised in parallel to the liberalisation process. The new entrants may be actors from other countries entering the market or new actors emerging. As markets remain small in most network industries, the number of actors is limited. In general, the market actors react to financial incentives, which can be either set by the consumers of the services or the public authorities paying for or subsidizing certain services.

The perception of performance and coherence varies between the actors (Asquer, 2011). Each actor will try to shape the co-evolution between institutions and technologies according to its interest. However, no actor – not even the political actors – has the ability to shape these dynamics within a sector by itself. Rather, it is all the actors together, behaving strategically vis-à-vis one another that shape the co-evolution, which should ensure the alignment between institutions and technologies.

Conclusion

Technology has to be supported by suitable institutions in order to generate the defined performance within a given network industry, and vice versa. This leads to the co-evolution between institutions and technologies. However, there may be cases where non-alignment (i.e., incoherence) between institutions and technologies leads to innovation (Jonker, 2010) and whilst temporarily reducing the alignment (i.e., coherence) it increases it over time. Too much non-alignment may lead to chaos within the network industry, but the absence of non-alignment may stop innovation. There might be an equilibrium which is time and sector-specific. Further research is clearly needed on the alignment/non-alignment topic, as well as on the causality between the alignment and the performance.

The coherence framework remains very conceptual. Further research by means of concrete case studies could render it more measurable and robust. Network industries could thus become comparable using the framework. Nevertheless, the framework underlines the need for alignment between technologies and institutions in the case of network industries. In this research, it serves to shape the research and guides the analysis by providing a lens to look at the alignment between institutions and the SHP technology and at the issue of further facilitation of SHP in Switzerland.

The research on SHP allows a concrete application of the coherence framework and, in a larger sense, the co-evolution literature. Some contributions could be done to improve the framework (see also Section 9.2). Furthermore, the research allowed working on the framework and thus further developing it as described in this Section.

Using the context described in Chapter 2, the technology in Chapter 4, the institutions in Chapter 5 and the theory developed in this Chapter, the alignment in the case of SHP is analysed in more depth in Chapter 6. During the research and with the co-evolution and coherence literature in mind, storage and pumped-storage SHP was identified as an example of co-evolution requiring a better alignment between institutions and technologies. This is developed in the later Chapters.

4. Small hydropower in Switzerland

Small hydropower (SHP) combines the advantages of hydropower with those of distributed power generation. SHP plants can be well integrated environmentally, have minor need for expensive maintenance and can be part of multipurpose infrastructures. However, most new projects are not cost-efficient in the current electricity market and require an adequate institutional framework to be implemented under financially viable conditions (see Chapter 5).

The government's aim to increase the weight of renewable energy technologies (RETs) and the possibility of multipurpose plants are opportunities for SHP. However, there are also threats from climate change (including the disruption of water supplies), from administrative barriers and from the significant environmental opposition which still continues. On a worldwide scale, SHP is certainly one possible way to enable broader access to distributed electric energy.

In this Chapter, the SHP technology is introduced, including a review of some current definitions and presentation of past and current R&D trends. The Swiss SHP history is briefly described, followed by current potential estimates.

4.1 Small hydropower technology

Small hydropower is the small scale application of the well-known hydropower technology. There are varied definitions and usages.

4.1.1 The definition of mini and small hydropower

There is no universally accepted definition of mini hydropower (MHP) and small hydropower (SHP). Table 4-1 summarises the different definitions related to the installed capacity around the world (by country and international organisation). The upper limit for SHP varies between 1.5 MW (Sweden) and 30 MW (Brazil and USA); for MHP 0.3 (Switzerland) and 10 MW (Madagascar). A maximum of 10 MW is the most widely accepted value worldwide for SHP.

Table 4-1: The different definitions of micro, mini and small hydropower in the World

Country / Organisation	Micro Hydro	Mini hydro	Small hydro	Source
Austria			< 10 MW	(Platform Water Management in the Alps, 2011b)
Brazil	<100 kW	100-1'000 kW	1-30 MW	(Moreire and Poole, 1993), http://www.cerpch.unifei.edu.br/en/oque.php [1]
China		<500 kW	0.5 – 50 MW	(Moreire and Poole, 1993; Dragu, Sels et al., 2001; IPCC, 2011)
ESHA	<100 kW	<500 kW	<10 MW	(Mazzetoo, Papetti et al., 2004)
France	5-5'000 kW		<12 MW . < 4.5 MW	(Moreire and Poole, 1993; Dragu, Sels et al., 2001; ESHA, 2004a) (Platform Water Management in the Alps, 2011b)
Germany			< 1 MW	(Platform Water Management in the Alps, 2011b)
IEA	<100 kW	100-1'000 kW	<10 MW	(IEA, 2003: 31)
India	<100 kW	100-1'000 kW	1-25 MW	(Purohit, 2008)
Italy			<3 MW	(ESHA, 2004a)
Madagascar		<10 MW	<20 MW	http://www.small-hydro.com/
Norway	<100 kW	100-1'000 kW	1-10 MW	(The Norwegian Water Resources and Energy Administration (NVE), 1991).
Spain, Portugal, Ireland, Greece, Belgium, Slovenia			<10 MW	(ESHA, 2004a), http://www.small-hydro.com/
Sweden			<1.5 MW	(ESHA, 2004a)
Switzerland		<300 kW	<10 MW	(BFE, 2008b: 7), www.admin.ch/ch/f/rs/c734_71.html
UK			<20 MW	(ESHA, 2004a)
UNFCCC			<20 MW	(Elsworth and Worthington, 2010)
US	<100 kW	100-1'000 kW	1-30 MW	(Moreire and Poole, 1993; Dragu, Sels et al., 2001)
World Bank	5-100 kW	100-1000 kW	1-10 MW	www.worldbank.org/re (April 2006)

[1] *According to the National Agency of Electrical Power, a small hydro plant is defined as (Resolution no. 394, of December 04, 1998): power equal to 1.0 MW and equal or inferior to 30.0 MW; with same or inferior total area of reservoir to 3.0 km^2; being delimited by the water quota associated to the flow of full with time of 100 year-old appeal. In the SHP Manual of Eletrobras (1982), the classification of MHP and SHP is also linked to the head: MHP 20-100 m; SHP 25-130 m.*

Remark: alphabetic order

Sources: in the table

The Swiss regulation specifies 10 MW as the upper limit for SHP. This capacity is the average gross capacity according to the Swiss Law[55]. For the statistics of the Swiss Federal Office for Energy (SFOE), the capacity is defined as the maximum possible capacity from the generator (Leutwiler, Bölli et al., 2011: 7).

According to the author of the latest Swiss hydropower research program (Jorde, 2007: 17), there is no sensible technical limit value based on the installed capacity between SHP and larger hydropower, but instead a relatively broad transition zone between 1 and 10 MW. However, such fixed value definitions are necessary for the implementation of policy instruments and for setting the institutional framework. The disadvantage of fixed valued definitions is that it can lead to the implementation of smaller plants which receive institutional incentives instead of constructing one or several larger plants which would technically and environmentally be the optimal solution for a given geographical site.

The **definitions** used in this thesis are, for MHP, an installed capacity of 100-1’000 kW and for SHP, 1-10 MW. This corresponds to the International Energy Agency and World Bank definitions. In the case of small hydropower, it corresponds as well to the Swiss and European Small Hydropower Association (ESHA) definition.

Some institutional frameworks take into account the production, thus link policy instruments to the electricity produced and not only to the installed capacity. The Swiss feed-in remuneration scheme, for example, applies a factor to the installed capacity based on the yearly production to obtain a so-called equivalent installed capacity which is referred to for the allocation of the feed-in remunerations (see Section 5.2.2).

4.1.2 The technology

SHP is wrongly considered as being a simple and a mature technology. It is actually affected by a multitude of disciplines such as hydraulics, mechanics, civil engineering, electrical engineering, biology, flood management, etc., which make SHP a complex technology. While already well developed, SHP still requires important R&D (see Section 4.1.6).

With hydropower the potential energy of water is transformed into mechanical or electric energy. There are different SHP categories. The SFOE differentiates three categories of hydropower plants depending on the kind of construction, head, and load factor (Piot, 2006a). In regard to the construction factor, there are:

- run-of-the-river plants where a river is dammed up and the water flows back into the river in less than 50 m distance;
- derivation plants where residual flow regulation applies (Leutwiler, Bölli et al., 2011);
- storage hydropower plants where the water is stored for a certain period of time (hours or even months);
- pumped-storage plants which consist of an upper and a lower reservoir thus pumping and turbining water between them (see also Section 7.1.2);
- “Umwälzwerke“ where only pumped water is used for electricity production between two reservoirs which form a closed system.

In regard to the load factor, if the factor is above 50%, the plant is called a base load plant. If the factor is below 30%, the plant is called a peak load plant. All others plants with load factors in between are called middle load plants.

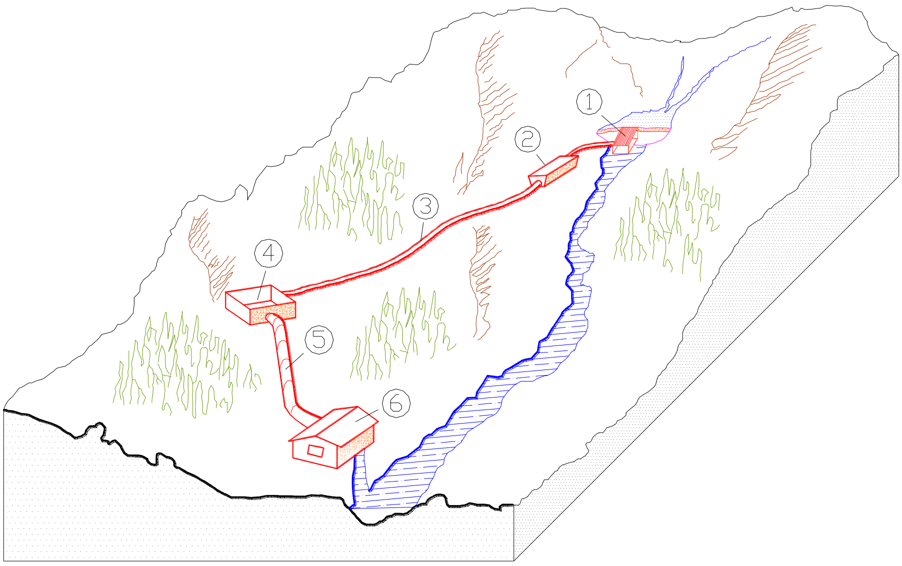
In regard to the head factor, low head hydropower plants have 40 m or less head. These are mostly run-of-the-river plants producing base load. Middle head plants have between 40 and 200 m heads and can produce base load or peak load. Above 200 m head, the hydropower plant is called high head and produces peak load (storage

[55] Definition according to Art. 51 of the Federal Water Rights Law of the 22 December 1916, SR 721.80 http://www.admin.ch/ch/d/sr/c721_80.html

and pumped-storage plants). There are various different limits between the types in the literature. These values from Piot are taken as they come from an official document of the SFOE (Piot, 2006b).

A further way to categorise SHP plants is based on their connection to the electricity grid. SHP plants can be off-grid, mini-grid or grid connected. In the case of off-grid, electricity is produced for one, or a limited number of users. In the mini-grid (e.g., local grid) and grid-connected cases, the electricity is provided to numerous users. In Switzerland, the electricity grid is well developed and reaches remote areas. Access to the grid is therefore not a problem for almost all new SHP plants.

Figure 4-1 shows the main components of one common type of SHP plant in Switzerland, a high head derivation SHP plant.



Source: (Andaroodi and Schleiss, 2005, p. 22)

Figure 4-1: Main components of a high head SHP plant

The water is diverted through a water intake in the river bank or bed (1). The water intake, which is generally built with concrete and can be integrated into the dam, removes solid materials such as wood and leaves from the water. The stability of the dam must be guaranteed in case of floods. A settling basin (2) is placed after the intake structure to remove sand particles from the flowing water. A headrace canal (3) then follows the contour of the hillside to provide the required head for electricity production. The water then enters a forebay (4) and passes into a closed pipe known as a penstock (5), made from steel or other high pressure resistant materials. This last structure is connected at a lower elevation to a turbine located in the power house (6). At the outlet of the turbine, the water is discharged back to the river, via the tailrace. The turbine is connected to a generator which, through a transformer, feeds the electricity into the grid. If necessary, a fish-bypass is integrated in the dam or in a side channel.

The turbine is the key component enabling the transformation of the kinetic energy of the water into mechanical rotational energy, which can be used to drive an electric generator, or other machinery. The power available is proportional to the product of head and flow rate. The formula for hydro system power output is given in the Equation (4-1).

$$P = \eta \cdot \delta \cdot g \cdot Q \cdot H \qquad (4\text{-}1)$$

Where:

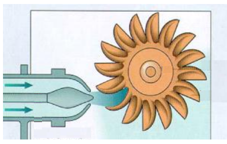
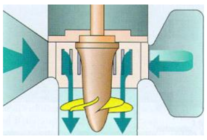
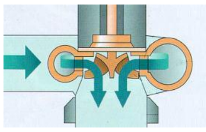
- *P stands for the installed capacity, i.e. the power [kW]*
- *η describes the overall efficiency of the system (generally around ~80% (Laufer, Grötzinger et al., 2004))*
- *δ is the water density [usually 1'000 kg/m^3]*
- *g is the gravity acceleration [9.81 m/s^2]*
- *Q is the volume flow rate passing through the turbine [m^3/s]*
- *H is the gross head of water across the turbine [m]*

To simplify the formula, a factor 8 can be introduced taking into account η, δ and g.

There are various types of turbines to cope with different levels of head and flows. The two broad categories are (SHERPA, 2008c):

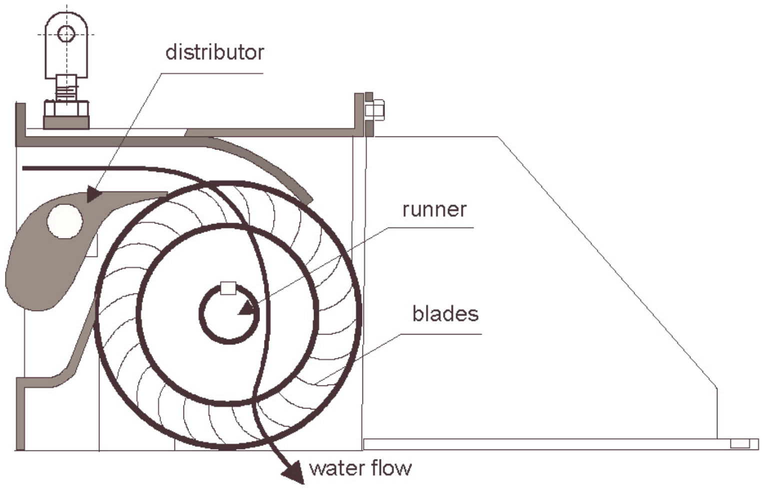
- **Impulse turbines**, such as Pelton, Turgo, Banki-Mitchell (cross-flow): Water impinges or enters the runner, which is designed to change the water's direction and thereby extract the momentum from it.
- **Reaction turbines**, such as Francis and Kaplan: They run full of water and in effect generate hydrodynamic "lift" forces to propel the runner blades, extracting thus the pressure energy of inflowing water.

Table 4-2: Pelton, Kaplan and Francis turbines

Type	**PELTON**	**KAPLAN**	**FRANCIS**
Figure	 	 	 
Description runners	The runner is composed of buckets.	The runner is composed of blades, bulbs and propeller runners. Axial or radial flow.	Fixed runners blades and adjustable guide vanes. Radial flow.
Head	High-head applications from 60 m to more than 1000 m.	Low-head applications from 1.5 m to 50 m.	Medium-head applications from 10 m to 500 m.

Sources: (Andaroodi and Schleiss, 2005: 24; SHERPA, 2008c)

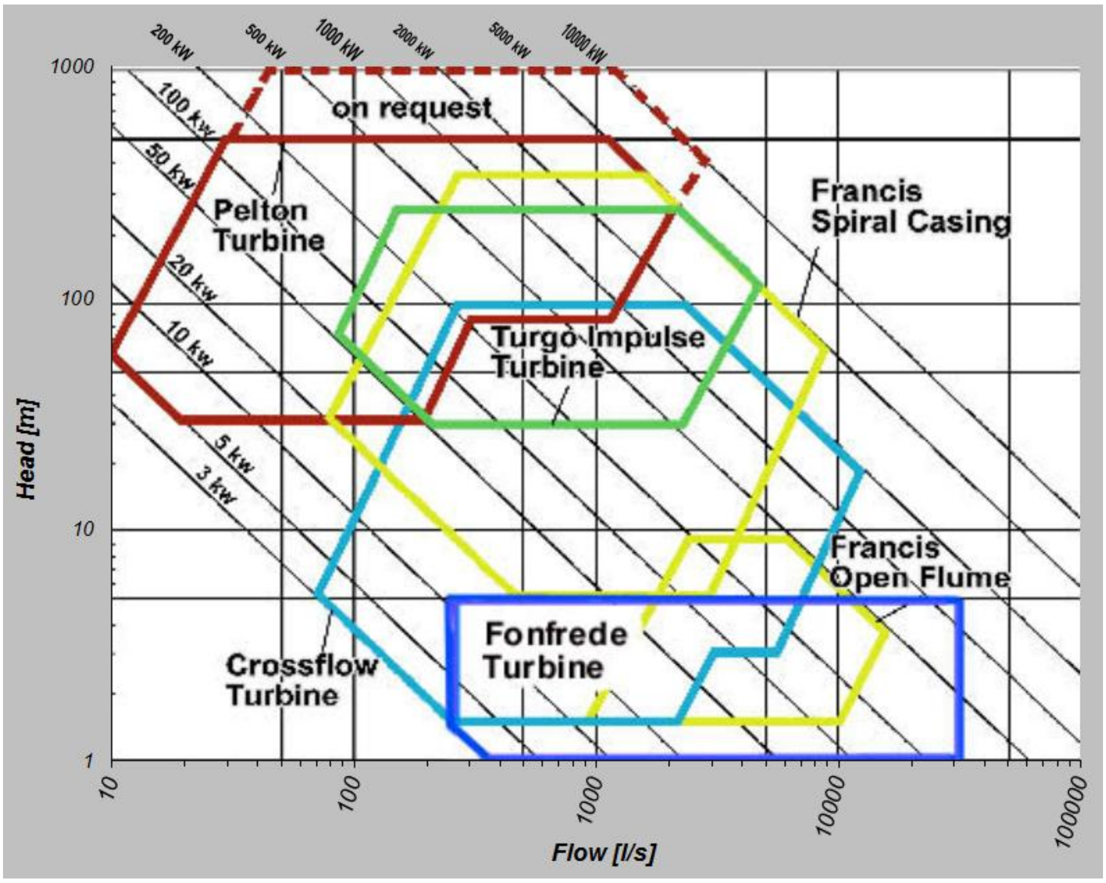
The Banki-Mitchell turbine is used for a wide range of heads overlapping those of Kaplan, Francis and Pelton. It can operate with heads between 5 and 200 m. The water enters the turbine, directed by one or more guide vanes located upstream of the runner and crosses it two times before leaving the turbine. The Ossberger turbines are a well-known example.



Source: (Andaroodi and Schleiss, 2005: 24)

Figure 4-2: Cross-Flow turbine (Banki-Mitchell)

Figure 4-3 shows the influence of head and flow on the choice of turbine. The choice can be optimised for a given site using hydraulic profiles such as those developed by the competence centre Mhylab (see Table 5-1) or numerical simulation.



Source: (Andaroodi and Schleiss, 2005)

Figure 4-3: Turbine choice according to head and flow

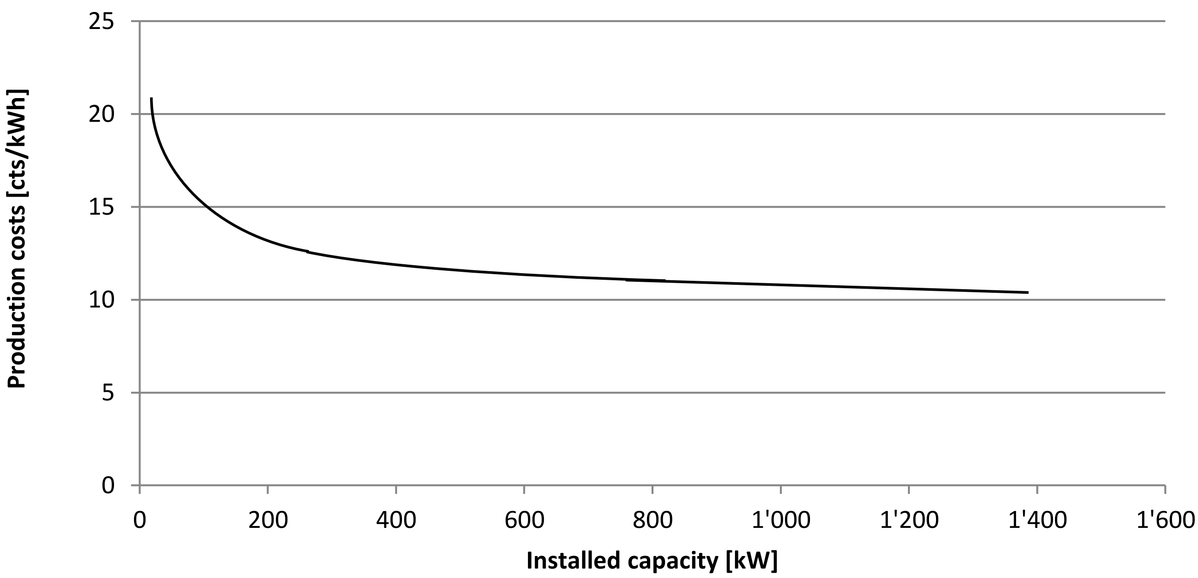
SHP plants are usually equipped with synchronous generators and thus operate the turbines at fixed speeds. To increase the efficiency and alleviate cavitation problems, variable speed generators can be installed (Paolone, Alberti et al., 2008). In addition, micro-controllers can be installed which increase the efficiency between a few % points in the case of constant flow and 12-20% in the case of variable flow (Paolone, Alberti et al., 2008). For MHP plants, asynchronous generators are the prevailing choice as they are a cheaper solution (Berizzi, Papetti et al., 2011).

For plants with an installed capacity below 200-300 kW, standardised construction and standardised electromechanical equipment are possible. Plants above 300 kW generally require individual design specific to the geographical site. Therefore, the smaller the plant, the more it can become a standardised product. For example, small MHP turbines can be produced in an industrial process once the prototype has proven to fulfil the technical requirements.

A new threat for SHP equipment could become the supply of rare materials. Examples are praseodymium, neodymium and samarium used in permanent magnets (U.S. Department of Energy, 2010). More and more SHP generators use permanent magnets, especially in the case of low rotation velocity to avoid velocity multiplicators. Thus, as for all RETs, consideration on the supply of the required raw materials is necessary for the further development of the technology.

4.1.3 Costs of SHP

Hydropower projects have a high initial investment followed by low operating costs. Compared to large hydropower plants, SHP plants are commonly associated with higher production costs due to their smaller size, and thus require institutional facilitation to compete on the market (see also Section 2.3 and Chapter 5). However, compared to other RETs, SHP has on average lower production costs (including financial costs) at 10-25 cts/kWh as shown in Figure 2-13. The production costs decrease with the increase in installed capacity as shown in Figure 4-4.



Source: (PSI, 2005: 111)

Figure 4-4: Indicative SHP production costs decreasing with the increase in installed capacity

The SHP production costs depend mainly on the investment costs. Their calculation varies if it is a new, a rehabilitated or a re-activated plant. Average production costs depending on the type of SHP plant and on the construction plan are given in Table 4-3. In comparison, the production costs for hydropower across all installed capacities is around 6 cts/kWh (Wyer, 2008: 219).

Table 4-3: Production costs depending on the type of SHP plant

Type	Installed capacity [MW]	Production costs [cts/kWh]	Comments
High and low head plant	< 10	4.8 – 24	Existing plant
	< 10	9 – 25	
	< 1	12 – 30	
	< 0.3	12 – 16	Rehabilitation or upgrade of plant
	< 0.3	16 – 40	
Waste water plant	0.016 – 0.9	9 – 85	If only 50% of the potential would be used, then maximum 20 cts/kWh.
Drinking water plant	0.001 – 2	5 – 23	

Sources: (PSI, 2005: 109; Leutwiler, Bölli et al., 2011: 48)

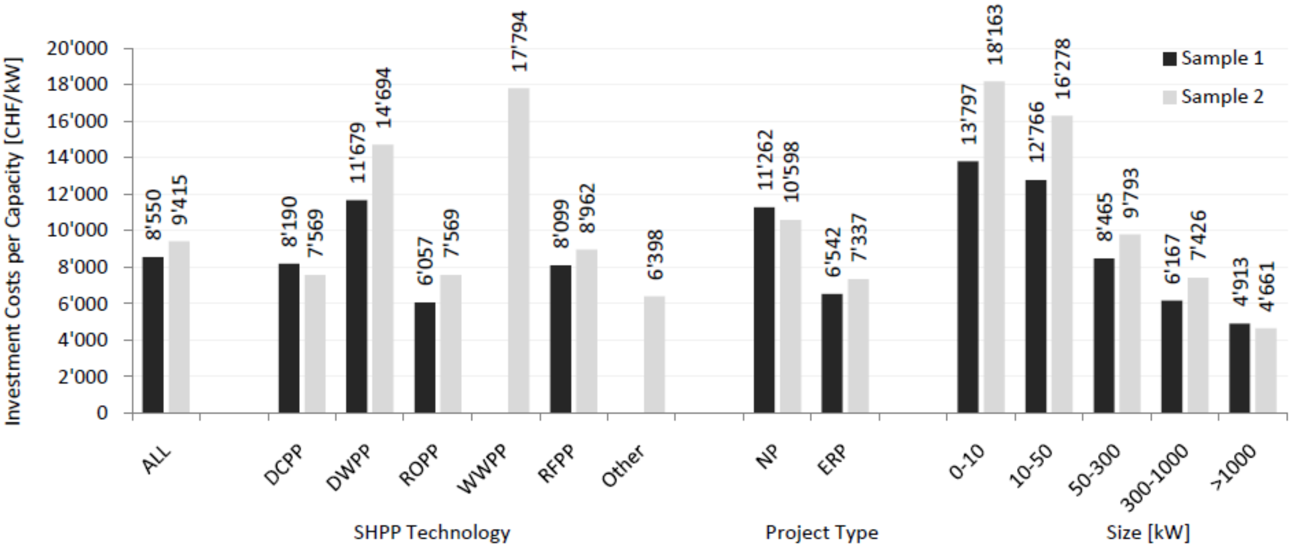
In the latest Swiss SHP handbook[56], Leutwiler et al. define five major costs factors (Leutwiler, Bölli et al., 2011: 48):

- Location: accessibility, slope geology, natural hazards, etc.
- Installed capacity: rule of economies of scale
- Gross head: higher pressures can be associated with smaller turbines and generators
- Degree of utilisation: proportional to energy specific investment costs
- Capital costs parameters: interest rate and time of depreciation

Kosnik showed that SHP is subject to nonlinear economies of scale, indicating that the very small plants are usually associated with significant costs per installed capacity (Kosnik, 2010).

The investment costs are usually depreciated over 10 to 20 years, whereas the lifetime of the infrastructure (the civil work parts) is over 50 years and can reach 80 years (PSI, 2005). The investment costs are mainly driven by the civil work costs (e.g., weir/dam, sand trap, pipes/penstock, forebay, water intake, fish-bypass, road access, power house, etc.), which can represent up to 80% of the total investment costs in the case of high head SHP plants. For the SHP plants receiving the feed-in remuneration (FIR) (see Section 5.2.2), these costs are in average between 50 and 60% of the total investment costs and increase with increasing size (Manser, 2011: 47). The second major cost function is the electromechanical equipment (e.g., turbine, generator, control system, etc.), which represents between 20 – 40% of the total investment costs and decreases with increasing size. The remaining costs account for engineering, construction management, administration and unforeseen costs. The investment costs are site-specific and thus difficult to standardise. In Switzerland, they vary between 6’000 and 15’000 CHF per installed kW (PSI, 2005). Figure 4-5 details the investment costs for the plants receiving the FIR.

[56] Further handbooks have been written by the European Small Hydropower Association (ESHA), Intelligent Energy Europe and the British Hydropower Association (Penche, 1998; ESHA, 2004b; BHA, 2005; SMART, 2009).



Legend:

-	*Sample 1:*	*SHP plants receiving the FIR in 2010*
-	*Sample 2:*	*SHP plants receiving the FIR and announced for the FIR in 2010*
-	*DCPP:*	*Derivation power plant*
-	*DWPP:*	*Drinking water power plant*
-	*ROPP:*	*Run-off power plant*
-	*WWPP:*	*Waste water power plant*
-	*RFPP:*	*Reserved flow power plant*
-	*NP:*	*New plants*
-	*ERP:*	*Expanded or renewed plants*

Source: (Manser, 2011: 45)

Figure 4-5: Median investment costs per kW installed capacity for different SHP plants

The operation and maintenance costs are typically 3 - 5% of the investment costs (ESHA, 2011). The Swiss SHP handbook divides them into civil work and electromechanical costs.

Table 4-4: O&M costs in percentage of investment costs of the components

Size	20 kW	100 kW	300 kW	1 MW	10 MW	100 MW
Civil work	3%	2%	1.5%	1%	0.8%	0.6%
Electromechanical equipment	4%	3%	2.7%	2.5%	2.5%	2.5%

Source: (Leutwiler, Bölli et al., 2011: 49)

The mean O&M costs of the SHP plants receiving the FIR in 2010 are 4.53% of the total investment costs, whereas the median O&M costs are at 2.35% (Manser, 2011). The standard deviation of 6.49% indicates the large variation between the different plants (109 plants for these survey results).

4.1.4 Environmental impacts

A main challenge of SHP is to find the right balance between ecology, electricity production and economy. SHP is strongly linked with the site-specific and local environment. Therefore, solutions have to be implemented which respect the initial state of the site concerning fauna, flora, river continuity, fish migration, noise emission and site aesthetics (SHAPES, Mhylab et al., 2010). The water resource has to be used in the most energy efficient way, thus producing a maximum of electric energy with the available water and head, while minimizing the negative environmental impacts and remaining cost-efficient. The environmental integration involves technical aspects such as fish-bypass and water intake, as well as non-technical aspects such as the definition of the appropriate minimum residual flow.

The environmental impacts of SHP plants are very site-specific and depend as well on the type of plants, e.g., storage or run-of-the-river, low-head or high-head and the length of the river diversion. If adequate measures are taken, the overall comparison of positive and negative environmental impacts can be balanced, and can be positive in cases for rehabilitation. Table 4-5 and Table 4-6 summarise the impacts during construction and operation.

Table 4-5: Environmental impacts during construction of a SHP plant

Events during construction	Persons or things affected	Impact	Priority
Geological Surveys	Wildlife	Noise	Low
Existing Vegetation Cutting	Forestry	Alteration of habitat	Medium
Enlargement of Existing Roads	General public	Creation of opportunities, alteration of habitat	Medium
Earth Moving	Site geology	Slope stability	Low
Tunnels Excavation	Site hydro-geology	Alteration of groundwater circulation	Low
Permanent Filling Material on Slopes	Site geology	Slope stability	Low
Embankment Realisation	Aquatic life, site hydro-morphology	Alteration of river hydraulic	Medium
Creation of Temporary Earth Accumulations	Site geology	Slope stability	Low
Realisation of Roads and Sheds for the Yard	Wildlife, general public	Visual intrusion, wildlife disturbance	Low
Watercourses Dredging	Aquatic ecosystem	Alteration of habitat	Medium
Temporary Diversion of Rivers	Aquatic ecosystem	Alternation of habitat	High
Use of Excavators, Trucks, Helicopters, Cars for the Personnel, Blondins	Wildlife, general public	Noise	High
Human Presence During the Works on Site	Wildlife, general public	Noise	Low

Source: (ESHA, 2004a)

Table 4-6: Environmental impacts during operation of a SHP plant

Events during operation	Persons or things affected	Impact	Priority
Renewable Energy Production	General public	Reduction of Pollutants	High
Watercourses Damming	Aquatic ecosystem	Modification of habitat	High
Permanent Work in the Riverbed	Aquatic ecosystem	Modification of habitat	High
Division of Watercourses	Aquatic ecosystem	Modification of habitat	High
Penstocks	Wildlife	Visual intrusion	Medium
New Electric Lines	General public wildlife	Visual intrusion	Low
Ripraps	Aquatic ecosystem, general public	Modification of habitat, visual intrusion	Low
Levees	Aquatic ecosystem, general public	Modification of habitat, visual intrusion	Low
Flow Rate Modification	Fish	Modification of habitat	High
	Plants	Modification of habitat	Medium
Noise from electromechanical equipment	General public	Alteration of life quality	Low
Removal of material from streambed	Aquatic life, general public	Improvement of water quality	High

Source: (ESHA, 2004a)

The impacts vary considerably between new projects and rehabilitation of existing plants, between projects with reservoirs (i.e. storage) and without, as well as between projects on rivers and within infrastructures. The impacts are lower for rehabilitation and projects within infrastructures, as well as for projects which do not significantly change the flow, i.e. without reservoirs.

The law prescribes a residual flow downstream of a water intake (see Section 5.2.2) to avoid drying out the river section that the water is diverted from. The residual flow is determined by the hydrology of the river and its freshwater ecology. The decrease in water changes the aquatic life and the water temperature, and can lead to the sedimentation of fine suspended materials and the increased growth of algae (PSI, 2005). To increase the residual flow means to decrease the renewable electricity production. Therefore, there is a balance to find between electricity production and environmental conservation.

In the case of a dam, the watercourse continuum is interrupted. This means that fish and other aquatic life cannot travel downstream or upstream. Measures such as fish-bypasses and fish-friendly turbines (to allow fish to swim through the water intake) are solutions to re-establish the watercourse continuum. Effective fish passage design for a specific site requires good communication between engineers and biologists, as well as thorough understanding of site characteristics (Andaroodi and Schleiss, 2005). If the turbine cannot be fish-friendly, constructive measures are required to lead the fish swimming downstream to the bypass. Fish-bypasses can become very costly and thus make the project financially unviable.

Reservoirs created by dams have the problem of sedimentation. Thus, regular flushing becomes necessary which should happen in times of floods in order to minimize the impacts on the aquatic life downstream (PSI, 2005).

If sites are located in inventoried Federal or Cantonal sites such as floodplains, moorland areas, and spawning areas, this is normally taken as a strong argument by the competent authority for rejecting applications. Details of the protected areas can be found online[57].

Finally, SHP plants should increase their environmental integration by burying pipes and reducing the noise of the powerhouse by adequate isolation.

4.1.5 Multipurpose infrastructures

SHP can be combined with other existing or planned infrastructures. These can be drinking, irrigation and waste water networks, as well as plants using the residual flow at larger hydropower plants (so called reserved flow schemes) and flood protection infrastructures. For example, when pipes have to be replaced in water networks, the hydropower component can be added if there is available head to use, thus influencing the pipe design. In other countries, SHP can also be combined with navigation locks and dams, as well as desalination plants. The Alpine Convention includes multipurpose SHP plants within its recommendations for the further SHP development in line with environmental considerations (Platform Water Management in the Alps, 2011a). The main advantages are:

- Use of existing or planned infrastructure. No new networks needed.
- No additional negative impacts on the environment.
- Limited investment for a SHP plant.

Furthermore, SHP can contribute to the cleaning of the river with the removal of rubbish at the water intake. In case of storage, the reservoir can be arranged as recreation area and be part of sustainable planning, or be part of flood protection measures. Examples of multipurpose plants can be found in Mhylab and ESHA (2010). This document also includes a guide on how to identify potential, develop the plant from a technical perspective and some institutional recommendations. The figures on installed capacities in Switzerland are given in Section 4.2.2. Section 8.1.2 develops some concrete multipurpose schemes.

The growth of the world’s population especially in developing countries will require the appropriate infrastructure for irrigation and water supply, as well as waste water treatment. This is a unique opportunity for multipurpose infrastructures with SHP to provide electrification as well. In developed countries, the optimisation of existing infrastructure and the added-value of SHP within existing networks are main drivers for multipurpose infrastructure development. In Switzerland, where many existing drinking and waste water networks will have to be upgraded, SHP plants could be integrated in the infrastructure.

4.1.6 Technological innovation

Today’s technological innovations are mainly generated by new environmental constraints and legislation, and the quest to increase efficiency and to reduce costs. The alignment between institutions and technologies in the case of SHP leans more towards the institutional side, which must further evolve to facilitate SHP, i.e. be aligned with small scale, distributed and RET electricity production. Therefore, the innovation aspect currently focuses more on institutions (see Chapters 5 and 6) and the technology can be seen as well developed (ESHA, 2006). However, SHP as a technology developed in an empirical way (Crettenand, Denis et al., 2011) and technical R&D in Switzerland began only a few decades ago. More systematic research is still needed (e.g., on turbines and the electromechanical part). Furthermore, large hydropower received historically significant R&D, but it must be noted that SHP is not just the downsizing of large scale hydropower and therefore requires its own R&D efforts. R&D is considered as being expensive and independent SMEs often cannot afford firm-intern research. R&D has

[57] http://umweltzustand.admin.ch/ubst.php?lang=en under “Water” (accessed on 02.11.2011)

therefore to take place either in large companies (e.g., Andritz[58], Alstom[59]) or in research laboratories (e.g., Mhylab[60]).

SHP is not just a product, but a technology consisting of numerous components (e.g., dam, pipes, turbine, etc.) and improvements can occur on any of those components; for example new fish-friendly turbines, electromechanical equipment or very low-head schemes. Much of the effort put into technological innovation focuses on improving the cost-effectiveness and environmental integration of the technology. From an institutional perspective, increased environmental integration decreases the importance of institutional barriers although it must remain economically viable for the project.

Among the innovation paths identified by Paish are (2002):

- Innovative use of existing civil works (e.g., siphonic turbine designs, drinking water networks for electricity production);
- Simplified and improved water intakes (e.g., self-cleaning trashraks);
- New materials for pipes (e.g., plastics and anti-corrosive materials);
- Low-head turbine development (e.g., diagonal turbine);
- Electronic control and telemetry (e.g., distant monitoring, automation);
- Innovation of electromechanical equipment (e.g., submersible turbo-generators);
- Innovation for environmental integration (e.g., fish-friendly turbines, fish-bypass).

In the past ten years, the technology continued to evolve and innovation has taken place along these paths, such as the multipurpose schemes (see also Section 7.3.1), fish-bypass systems and new turbine designs. New fish-bypass schemes such as vertical slot pass or the Denil-pass guarantee high fish acceptance while reducing the amount of bypass operation flow (ESHA and MHyLab, 2006). Very low head eel-friendly turbines[61] or infrared fish-fences[62] improve the environmental integration.

Site-specific R&D, which is used for large hydropower, is far too expensive for SHP. Therefore, other methods are required for R&D, such as for turbines. According to Mhylab, turbine R&D for SHP must lead to the three following outputs (Crettenand, Denis et al., 2011):

- high efficiency: optimal use of water resources,
- simplicity: costs reduction and feasibility for small and medium enterprises,
- maximum reliability: minimum and easy maintenance.

The method to design turbines is not standardisation (except below 200-300 kW), but systemisation. It is based mainly on laboratory development. It can be summarised as follows (Crettenand, Denis et al., 2011):

1. The re-sizing, simplifying and adapting of hydraulic technology from large turbines.
2. Real model testing with measurement of the adaptation impact and definition of an optimum output/manufacturing cost ratio.
3. Designing site specific prototypes using hill charts and similitude laws according to the international related standards.

The R&D costs to optimise turbines have to be compared to the potential energy gains due to the improved efficiency. When additional R&D costs cannot be recovered, the research is stopped.

[58] www.andritz.com (accessed on 02.11.2011)
[59] www.alstom.com (accessed on 02.11.2011)
[60] www.mhylab.com (accessed on 02.11.2011)
[61] www.vlh-turbine.com (accessed on 02.11.2011)
[62] www.profish-technology.be (accessed on 02.11.2011)

A new opportunity of turbine R&D are variable speed pump-turbines. The application is for pumped-storage schemes. Such pump-turbines are currently developed for large scale hydropower, but no R&D is yet done for the small scale application (see also Chapter 7).

In the range of MHP, the Hydromatrix turbine-generator can be seen as an innovation. The turbine-generators are within the same unit. Depending on the available flow, several units can be installed in parallel[63]. The whole unit is very compact. The StrafloMatrix has an integrated turbine runner-generator rotor design, where the outer edge of the turbine blade supports the generator rotor and both turn under flow as a single unit (PSI, 2005).

Beside the turbine, generators and transformers are also subject to much R&D. New high poly synchronous generators with permanent magnet excitation are designed for direct grid connection or in combination with a frequency converter for variable speed operation (ESHA and MHyLab, 2006). Such generators allow avoiding speed increasers. Oil-free transformers are an innovation towards more environment-friendly SHP plants.

ICT also improves the technology by introducing new options of remote control and monitoring. Any malfunctioning can be detected and the information made accessible instantly. Furthermore, it can offer site-specific optimisation including hydrological and market data into the operation of the plant. The aim is to reduce human control and monitoring in order to reduce operational costs.

Further innovation is still needed and the proposals for R&D for SHP as suggested by Mhylab and ESHA (2005) are still valid[64] (e.g., development of standardised hydraulic structures, low-head and very-low-head turbines, adaptation of low-speed generators, etc.). Some developments can be tested with demonstration plants before being implemented on real projects. In Switzerland, the current fields of technological innovation are mentioned in research program hydropower 2008-2011 (Jorde, 2007). The document suggests innovation in hydraulic construction and mechanical equipment.

At the International Congress Hidroenergia 2010 for small hydropower[65], the latest technological developments were presented. A EU funded research project (SHAPES in FP6) summarised the current R&D activities in the EU, Switzerland and Norway between 1998-2010 (SHAPES, Mhylab et al., 2010): 41% of the projects are for electromechanical equipment (79% turbine) and only 11% for civil works (water intakes, weirs, environmental integration, penstock). The remaining projects are on soft aspects (administration, topography, information dissemination) and environmental issues. Most R&D activities are in Germany, Italy, France and Switzerland. A few R&D examples are:

- Standardised low-head turbine
- Automation with ICT
- GIS-tools to assess SHP potential
- More efficient generators

Research on patents linked to past innovations for SHP showed few results[66]. As SHP is a bundle of components, there is no single patent regarding a whole SHP plant. In certain cases, several components have been patented together, e.g. the case of the StrafloMatrix (see above) whereby the whole electromechanical part was patented. Most patents relate to the electromechanical equipment and are linked to hydropower in general. Some patents relate to the specific use of SHP with wind power, with a siphon, with underground storage, with a water mill, with a sewage plan, and with video monitoring and tele-mechanical systems.

[63] www.hydromatrix.at (accessed on 02.11.2011)
[64] Discussion with Vincent Denis, Director of Mhylab, Montcherand, 29.04.2010.
[65] http://2010.hidroenergia.eu/ (accessed on 02.11.2011)
[66] Research done on World Intellectual Property Organization (WIPO) database (http://www.wipo.int/ipdl/en/index.jsp : research done on the 08.03.2010) and Espacenet ([66] http://ep.espacenet.com/advancedSearch?locale=fr_ep : research done on the 12.03.2010)

During the interviews mentioned in Section 1.6, the following question "where does the technology need to evolve" was asked. Only one person judged the SHP technology as mature not needing more R&D[67], while the others were still envisioning innovation opportunities and some are involved themselves in R&D. The following priorities were identified:

- reduce the production cost, especially for low-head schemes, with cheaper construction materials and increased reliability;
- increase the environmental integration with better performance of the different components (e.g. banning mineral oil and greases), bioengineering and improved passages for fishes (upstream and downstream), aquatic life (e.g. oxygen content in the water), bed load transport and sedimentation;
- improve the turbine technology for low-head schemes;
- simplify and make cheaper ICT in order to improve the tele-management of SHP plants.

SHP developers and persons representing the electricity sector aim at reducing costs while increasing the electricity production. Persons from the environmental side, such as environmental NGOs and public environmental services, stress the importance of the environmental integration, as well as the spatial planning and the need of broader approach than just a single project development. This is further elaborated in the following Chapters.

Finally, the survey results underline that technical standardisation is not necessarily the way forward for SHP as only 16% were in favour of it (Manser, 2011, Question 7.2b). The above developed systemisation is thus more appropriate.

4.1.7 Strengths and weaknesses of SHP

Concluding the technology description, Table 4-7 shows the main strengths and weaknesses of SHP in Switzerland.

Table 4-7: Strengths and weaknesses of SHP

Strengths	Weaknesses
- SHP is a renewable energy technology - SHP has a very high efficiency[1] - SHP has a high energy payback ratio - SHP has very low CO_2-emissions - SHP is indigenous and contributes to the security of supply - SHP brings employment to local firms as generally more than 50% of the investment costs is civil work - SHP can be integrated into multipurpose infrastructures - SHP plants have a long lifetime	- impact on the environment and landscape (although the negative aspect of this can be limited using the right measures) - the electricity production depends significantly on hydrology - higher production costs compared to conventional electricity production[2] - significant environmental opposition - sediments can fill the reservoirs in storage schemes - a few large scale hydropower plants might be a more economically efficient and ecologically sensitive way of reaching RET targets than a larger number of SHP plants - SHP can fragment the river basin if there is no regional spatial planning and regional policy making

[1] Compared to other technologies producing electricity, hydropower transforms the available energy into electric energy very efficiently (efficiency above 80% (SHERPA, 2008c)).

[2] However, the production costs are in average lower than other RETs.

[67] Interview CH-1

4.2 History and potential of SHP

This Section describes the SHP history in Switzerland and discusses the SHP potential, including more details on the Canton of Valais. SHP in Europe and worldwide is briefly reviewed.

4.2.1 History in Switzerland

Hydropower has a long history. The first hydraulic machines used in China and the Mediterranean basin date from 200 B.C (Andaroodi and Schleiss, 2005). The first hydropower plant in Switzerland was installed 1879 in St. Moritz with a capacity of 7 kW (Gredig and Walter, 2006). In the early 20th century, many mechanical power transmissions were replaced by electrical machines and there were nearly 7’000 SHP plants in Switzerland of which more than 90% were rated below 300 kW and consisted of water wheels and mini turbines (Leutwiler, 2006). They provided distributed electricity mainly for the craft sector and the local industry.

The development of hydropower in Switzerland over the last 60 years can be summarised in four periods (BFE, 2007c):

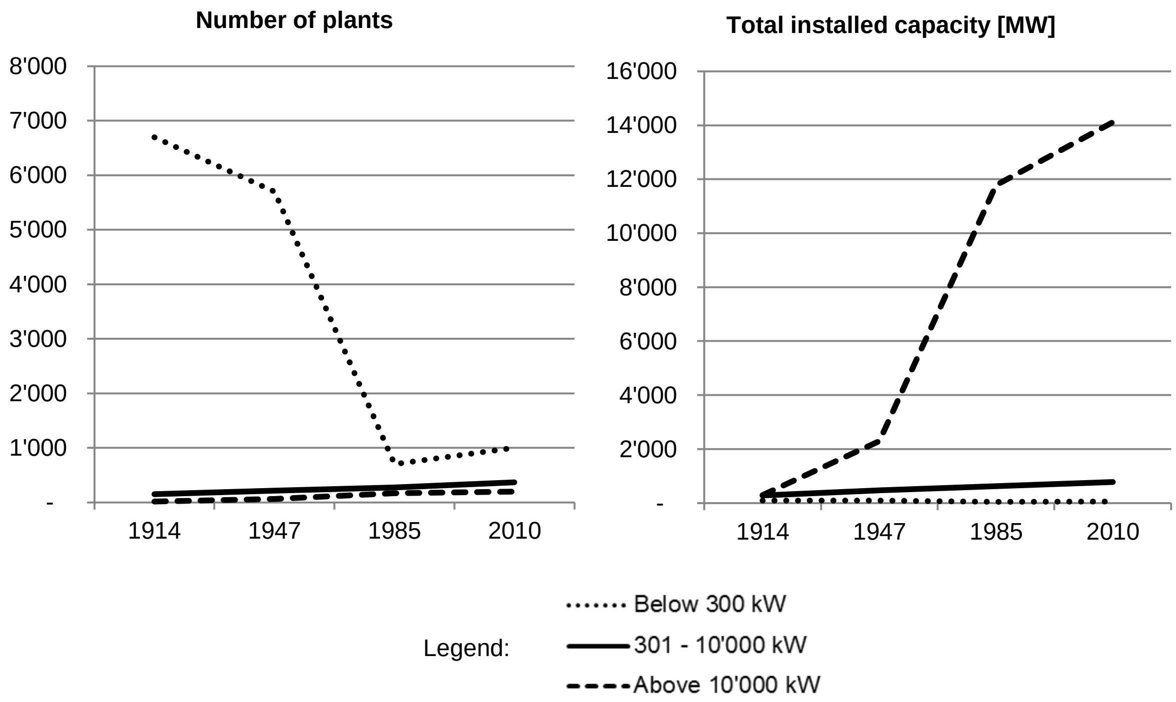
- 1955-1970: Intensive expansion of hydropower in Switzerland. The development was triggered among others by the strong increase of electricity demand, attractive economic frameworks, and lack of competing technologies.
- 1970-1980: The expansion slowed significantly because of the macro-economic situation, the intensive expansion of nuclear power and the increasing critical view of the population towards large hydropower schemes.
- 1980-1990: The construction activities almost stopped because the most interesting sites were already used, the high inflation rate led to high financial costs and the increase of the electricity demand diminished.
- 1990-2007: The institutional changes within the liberalisation process across Europe led to uncertainties. The over capacity started to decrease, and the importance of peak generation increased. The uncertain juridical and financial frameworks led to higher investment costs. On the other hand, the institutional facilitation of SHP led to further deployment of small scale plants (compare Table 4-8 and Table 4-9).

Table 4-8 and Figure 4-6 retrace the history during the 20th century when the number of operated MHP plants below 300 kW strongly decreased. This was due to the introduction of cheaper electricity from large scale power plants and the expansion of the grid, as well as the cheaper and more flexible combustion engines and cheap fossil fuel. In 1985, about 700 SHP plants below 300 kW remained. The trend changed again in the 1990s with the institutional changes. The Energy Article was included in the Swiss Federal Constitution and further legislation followed (see Section 5.2.1) leading among others to the facilitation program “Energy 2000” (including the DIANE program) and recently to the FIR. Such institutional facilitation contributed to develop MHP again. More details on the institutional framework and history follow in Chapter 5. The number of SHP and large hydro plants increased steadily during the 20th century, whereby the installed capacity of large hydro increased significantly.

Table 4-8: SHP and total hydropower in Switzerland during the 20th century

Installed electrical capacity (kW)	1914		1947		1973		1985	
	Plants	MW	Plants	MW	Plants	MW	Plants	MW
Below 300	~6'700	85	~5'700	85	~1'900	50	~700	46
301 - 1'000	87	46	116	68	126	72	127	74
1'001 - 10'000	67	229	102	407	139	518	147	550
Above 10'000	14	290	65	2'300	163	10'040	171	11'780
Total till 10'000	**~6'846**	**360**	**~5'930**	**560**	**~2'140**	**640**	**980**	**670**
Total hydropower	**~6'860**	**650**	**~6'000**	**2'860**	**~2'300**	**10'680**	**~1'150**	**12'450**

Source: (Leutwiler and Dasen, 2008)



Source: (Leutwiler and Dasen, 2008; BFE, 2011g, 2011e; Manser, 2011)

Figure 4-6: Hydropower in Switzerland since 1914: number of plants and installed capacity

Table 4-9 shows the hydropower data in 2010, whereby MHP represented 2.2% of the Swiss hydropower production and 1.2% of the total electricity production; SHP 7.9% and 4.4%. Therefore in 2010, hydropower below 10 MW represented about 10% of the hydropower production and 5.7% of the total electricity production in Switzerland (3'770 GWh). In comparison, wind power represented 0.05% and photovoltaic power 0.13% of the total electricity production (see Figure 2-7 and Figure 2-12).

In the case of multipurpose infrastructures, SHP within drinking water networks produced 107 GWh a year (Freiburghaus, 2011)[68] and SHP within waste water networks 5 GWh a year (PSI, 2005).

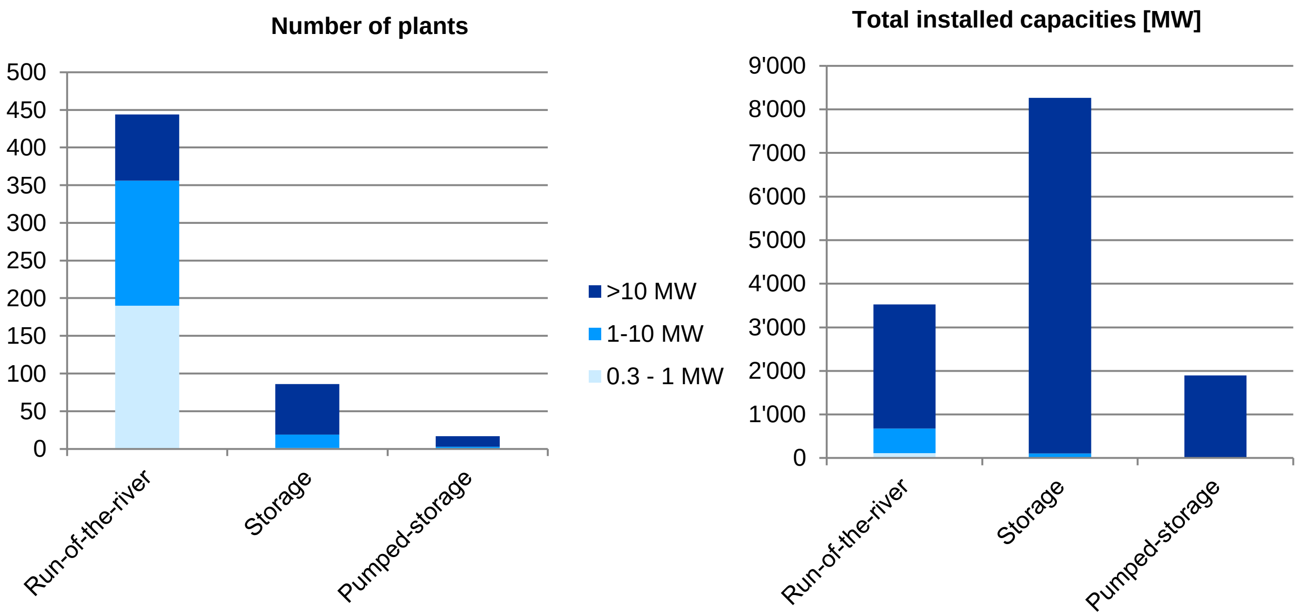
[68] The provision of a cubic meter of drinking water from the source to the tap requires in average 0.36 kWh of electricity in Switzerland. This adds up to an overall consumption of 350 GWh per year (Freiburghaus, 2011).

Table 4-9: SHP and total hydropower in Switzerland in 2010

Installed electrical capacity (kW)	2010				
	Plants	MW	GWh / year	Total electricity production from hydro-power	Total electricity production
Below 300	~1’000	60	270	0.7%	0.4%
301 - 1'000	191	110	554	1.5%	0.8%
1'001 - 10'000	187	689	2'947	7.9%	4.4%
Above 10'000	169	12'882	33'730	89.9%	50.9%
Total till 10'000	**1'378**	**859**	**3'770**	**10.1%**	**5.7%**
Total hydropower	**1'547**	**13'741**	**37'500**	**100.0%**	**56.6%**

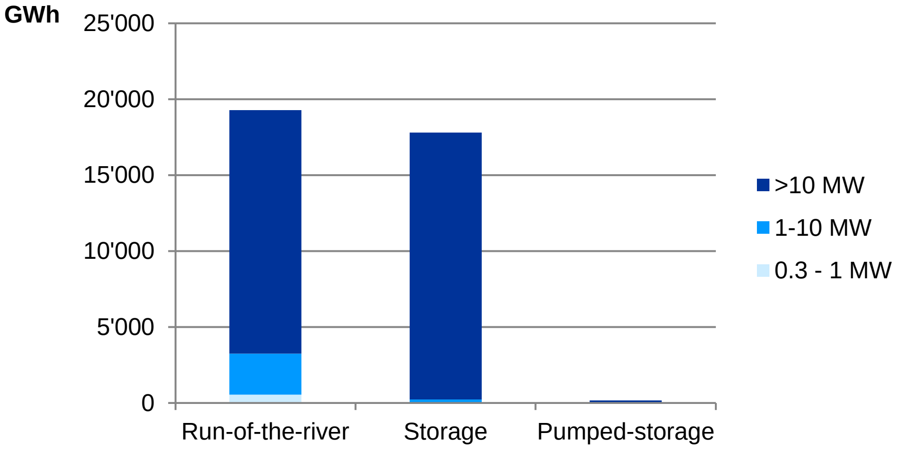
Source: (Leutwiler and Dasen, 2008; BFE, 2011g, 2011e, 2011d; Manser, 2011)

Figure 4-7 shows the number of MHP, SHP and large hydropower plants per category (run-of-the-river, storage, and pumped-storage), as well as the total installed capacities (see also Table 7-1). Figure 4-8 presents the yearly production, whereby, in the case of pumped-storage plants, the pumping energy is not subtracted. MHP above 300 kW accounts mainly for run-of-the-river plants representing about 42% of the number of plants. SHP accounts for about 37% of the number of run-of-the-river plants, which represents about 16% of the installed capacity and 14% of the production of run-of-the-river plants. SHP also contributes to total number of storage plants with 18 plants. Large hydro accounts mainly for the installed capacity and production for all three categories.



Source: (BFE, 2011g)

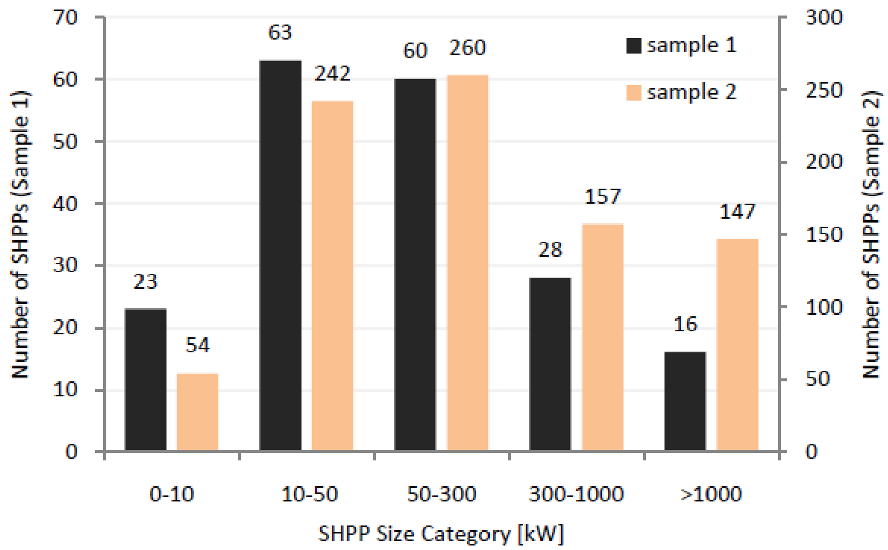
Figure 4-7: Number of hydropower plants and installed capacities in Switzerland in 2010



Source: (BFE, 2011g)

Figure 4-8: Annual production of hydropower plants in Switzerland in 2010 (GWh)

The Small Hydropower program (see Section 5.2.2) was aimed to establish a national database with all SHP plants[69]. Unfortunately, the database was started but never completed. Today, the most exhaustive database comes from the SFOE and is called the Statistic of the Hydropower Plants in Switzerland (in German "Statistik der Wasserkraftanlagen der Schweiz (WASTA)")[70]. The power plants from an installed capacity of 300 kW and above are registered. For the information for MHP plants below 300 kW, the current most accurate data come from the SHP umbrella organisation ISKB[71]. Some data can also be obtained thanks to the newly introduced FIR. Figure 4-9 shows the distribution of the plants depending on their installed capacity. It can be clearly seen, that plants below 300 kW are strongly facilitated with the FIR and increase in numbers again. However, their facilitation from an economic perspective can be debated as Figure 4-10 shows the negative NPV per kW. The 146 plants below 300 kW receiving the FIR in 2010 have a total installed capacity of 9.1 MW and produced 43.2 GWh in 2010 (Manser, 2011).



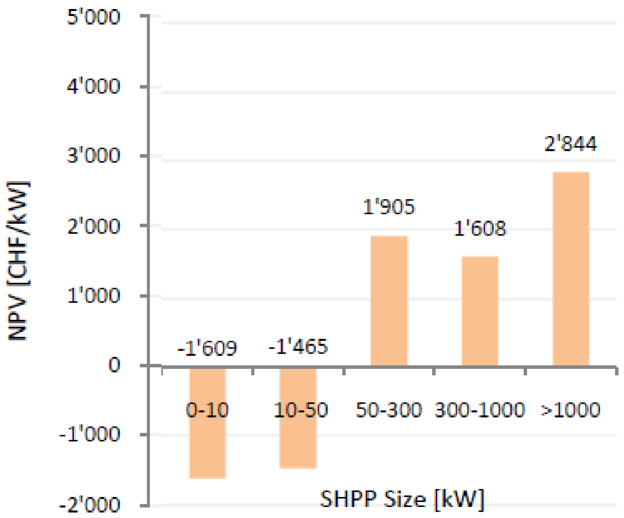
Legend:

- Sample 1 are the plants in operation or soon to be in operation in 2010 (N=190)
- Sample 2 are all plants either in operation, soon to be in operation, announced or in the waiting list (N=860)

Source: (Manser, 2011)

Figure 4-9: Number of SHP plants per size category receiving the FIR in 2010

[69] www.kwkatlas.ch (accessed on 03.11.2011)
[70] http://www.bfe.admin.ch/themen/00490/00491/index.html?lang=de&dossier_id=00857 (accessed on 03.11.2011)
[71] http://www.iskb.ch/



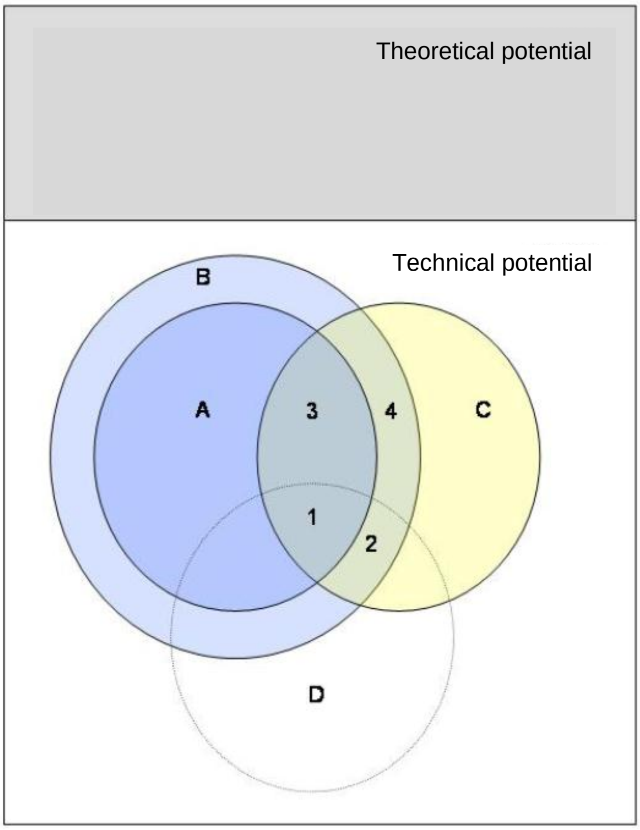
Source: (Manser, 2011)

Figure 4-10: Net present value (NPV) per installed capacity per SHP size category for plants receiving the FIR in 2010

The FIR plants (number of plants, installed capacity, production) according to their category (run-of-the-river, derivation, drinking water, etc.) are given below in Table 4-11.

4.2.2 Potential in Switzerland

The theoretical potential of a given technology is represented by the main rectangle of Figure 4-11. In the case of SHP, it is the potential power and production based on the available head and flow (see Equation (4-1)). Part of the theoretical potential is technically feasible, therefore leading to the technical potential (white rectangle). Within the technical potential four further potentials are included. Circle A represents the economic potential in a given context. B is the enlarged economic potential (e.g., economic potential created by specific incentives to facilitate the chosen technology, e.g. FIR). C represents the ecological potential (e.g., what is ecological acceptable) and D represents the “societal-acceptance” potential which is a more fluid concept. The overlapping of these four potentials within the technical potential lead to the usable potential (1, 2, 3 and 4) and finally to the expected potential (1 and 2).



Source: (Piot, 2006b)

Figure 4-11: The different potentials

The research presented in this thesis aims, among other contributions, to contribute to increase the economic and enlarged economic potential (e.g., for the former CO_2 compensation and for the later FIR improvements – see Chapter 6), as well as the "societal-acceptance" potential. The environmental potential is studied by the research of Hemund (Hemund and Weingartner, 2012). Within the particular focus on storage and pumped-storage application, the technical potential is evaluated (see Section 8.1).

The potential of hydropower on a river section can either compete with or be complementary to other uses of the water. For example, storage SHP can be complementary to flood protection measures. On the other hand, agriculture, drinking water supply and the protection of landscapes compete with hydropower.

The potential of large hydropower is largely fulfilled in regard to the number of plants already in operation. However, rehabilitation and upgrading of existing plants can increase the production. SHP still has significant untapped potential on low-head sites, some high-head sites, within infrastructures and through rehabilitation of abandoned or out-dated sites.

The last in depth study of the SHP potential goes back to 1987 (Desserich and Funk). The technical SHP potential in Switzerland was evaluated around 9 TWh/year, whereby approximately 3 TWh/year were actually used. In November 2008, the Swiss government initiated a new study with WaterGisWeb Ltd on the evaluation of the remaining potential of SHP in Switzerland. Based on a GIS-analysis and considering all streams with a minimum length of 500 m, the theoretical SHP potential is evaluated. Existing plants and registered protected river sections are also considered. The results are expected in spring 2012.

The latest publically available evaluation from SFOE gives 1.9 TWh as additional expected SHP potential till 2050 compared to 2010 (BFE, 2011a), an increase of about 50%. However, this evaluation has been revised to 1.2 TWh with the current institutional framework and 1.7 TWh with an improved institutional framework[72].

2050 is far away and evaluations for 2030/2035 have been conducted in the recent years. The SFOE and EnergieTrialogSchweiz evaluated the SHP production in 2035 at around 4.9 to 5.0 TWh (BFE, 2007b; Energie Trialog Schweiz, 2009), which are about 1.2 to 1.3 additional TWh compared to 2010 (+30 to 33%). The economic potential in 2030 has been evaluated at 4.9 TWh (Ernst Basler + Partner, 2009). The PSI summarised the technical potential for SHP, MHP and plants below 300 kW in Table 4-10. Plants on drinking and waste water networks are included as well. It can be noted that MHP contributes to about 20% of the technical SHP potential in 2035, whereby plants below 300 kW represent 45% of the MHP potential.

Table 4-10: SHP technical potential in Switzerland

Technical potential (GWh/year)	2004 (in operation)	2020	2035
< 10 MW	3'422	4'700	5'600 - 6'800
< 1 MW	781	860	920
< 300 kW	300	380	420
Drinking water SHP	65	120	155
Waste water SHP	5	15	25

Source: (PSI, 2005)

Following the introduction of the FIR in 2009, the additional potential of SHP can also be evaluated by the projects already announced and by projects on the waiting list (see Section 5.2.2 for more information on the scheme). Each SHP plant applying for the FIR has to be announced at the Swiss TSO (Swissgrid). Swissgrid monitors the waiting list on its website for projects that are announced but for which no funding is currently available[73]. The data at the beginning of 2012 are shown in the Table 4-11. 484 GWh are financed through the FIR.

Table 4-11: SHP plants and their status related to the feed-in remuneration on the 18.01.2012

	Waiting list	Announced	Planned	In operation	Total
Number of plants	335	385	12	245	**977**
Capacity [MW]	222	339	9	106	**676**
Production [GWh]	895	1'338	44	484	**2'761**

Source: https://www.guarantee-of-origin.ch/reports%5CDownloads%5Cwarteliste_DE.pdf (accessed on 19.01.2012)

Taking into account the ecological and partly the societal-acceptance potential, the WWF conducted an evaluation in 2010 of the FIR projects and estimated the expected potential for additional production at 1'100 GWh (Ernst Basler + Partner, 2010), which was about 50% of the announced projects and projects on the waiting list at that time.

[72] Workshop "Energiestrategie 2050: Wasserkraftpotenzial der Schweiz", Bern, 15.11.2011, and
Presentation of the results of the survey "Wasserkraftpotenzial der Schweiz", SFOE, Ittigen, 14.02.2012.
(The environmental NGOs (WWF, ProNatura, Rheinaubund) evaluate the maximal potential between 0.7 and 1.0 TWh, whereas the electricity utilities evaluate the potential between 1 and 2 TWh.)

[73] https://www.guarantee-of-origin.ch/reports%5CDownloads%5Cwarteliste_DE.pdf (accessed on 03.11.2011)

To account for the differentiation between SHP on streams and within infrastructure, the FIR projects can be divided into several categories. Table 4-12 shows the number of projects at the end of 2010; more recent data is not available. About 56% of the projects were on streams and accounted for 88% of the total installed capacity and 86% of the total production. This comes from the fact that the median installed capacities for infrastructures plants is significantly smaller than for plants on streams (i.e. around 50 kW in infrastructure to 400 kW on streams). However, there is a non-negligible potential with drinking water networks, whereby about a third of the projects are already in operation.

Table 4-12: SHP plants and their status per category related to the FIR on 01.01.2011

Type of SHP plant		Waiting list	Announced&Planned	In operation	Total
SHP plant on streams	Number	196	194	98	**488**
	Capacity [MW]	210.7	252.6	57.7	**520.9**
	Production [GWh]	803.9	999.9	267.4	**2'071.2**
SHP plant in drinking water networks	Number	117	107	85	**309**
	Capacity [MW]	13.8	12.5	8.3	**34.7**
	Production [GWh]	87.0	57.8	37.4	**182.2**
SHP plant in waste water networks	Number	5	4	2	**11**
	Capacity [MW]	0.4	1.6	0.5	**2.5**
	Production [GWh]	1.8	4.8	1.1	**7.7**
Other SHP plant	Number	21	26	5	**52**
	Capacity [MW]	7.7	21.8	2.8	**32.4**
	Production [GWh]	34.4	95.6	15.6	**145.5**
TOTAL	**Number**	**339**	**331**	**190**	**860**
	Capacity [MW]	**232.6**	**288.5**	**69.3**	**590.4**
	Production [GWh]	**927.0**	**1'158.0**	**321.5**	**2'406.5**

Source: (Manser, 2011)

Not all projects which are announced or in the waiting list will be built. Therefore, an adjustment factor is introduced as shown in Table 4-13. Several reasons account for this. Firstly, more projects have been announced or are in the waiting list than are technically feasible. Competitors identified projects on the same river section and announced several projects to Swissgrid for exactly the same site or close by. Some companies even announced several projects for the same site in order to have time to further evaluate the optimal installed capacity with the option of withdrawing their abandoned projects from the list at a later date[74]. Secondly, some projects are ecologically not feasible because of their situation in protected areas. Thirdly, the water concession and construction permits still have to be obtained before construction. Finally, opposition to projects may render them not feasible from a societal-acceptance perspective.

[74] In the initial design of the FIR scheme the installed capacity had to be given within a chosen range and could not be changed beyond certain values. The reviewed scheme allows changes without boundaries (see Section 5.2.2).

Table 4-13: SHP projects related to the FIR on the 18.01.2012 – adjusted forecasts

	Waiting list	Announced	Planned	Total	Total adjusted[1]
Number of plants	335	385	12	**732**	**373**
Capacity [MW]	222	339	9	**570**	**294**
Production [GWh]	895	1'338	44	**2'277**	**1'178**

[1] *Adjustment factors (discussed with Bernhard Hohl, SFOE, 02.03.2011, and calibrated with FOEN evaluation November 2011):*

- *90 % planned plants*
- *55 % announced plants*
- *45 % plants on the waiting list*

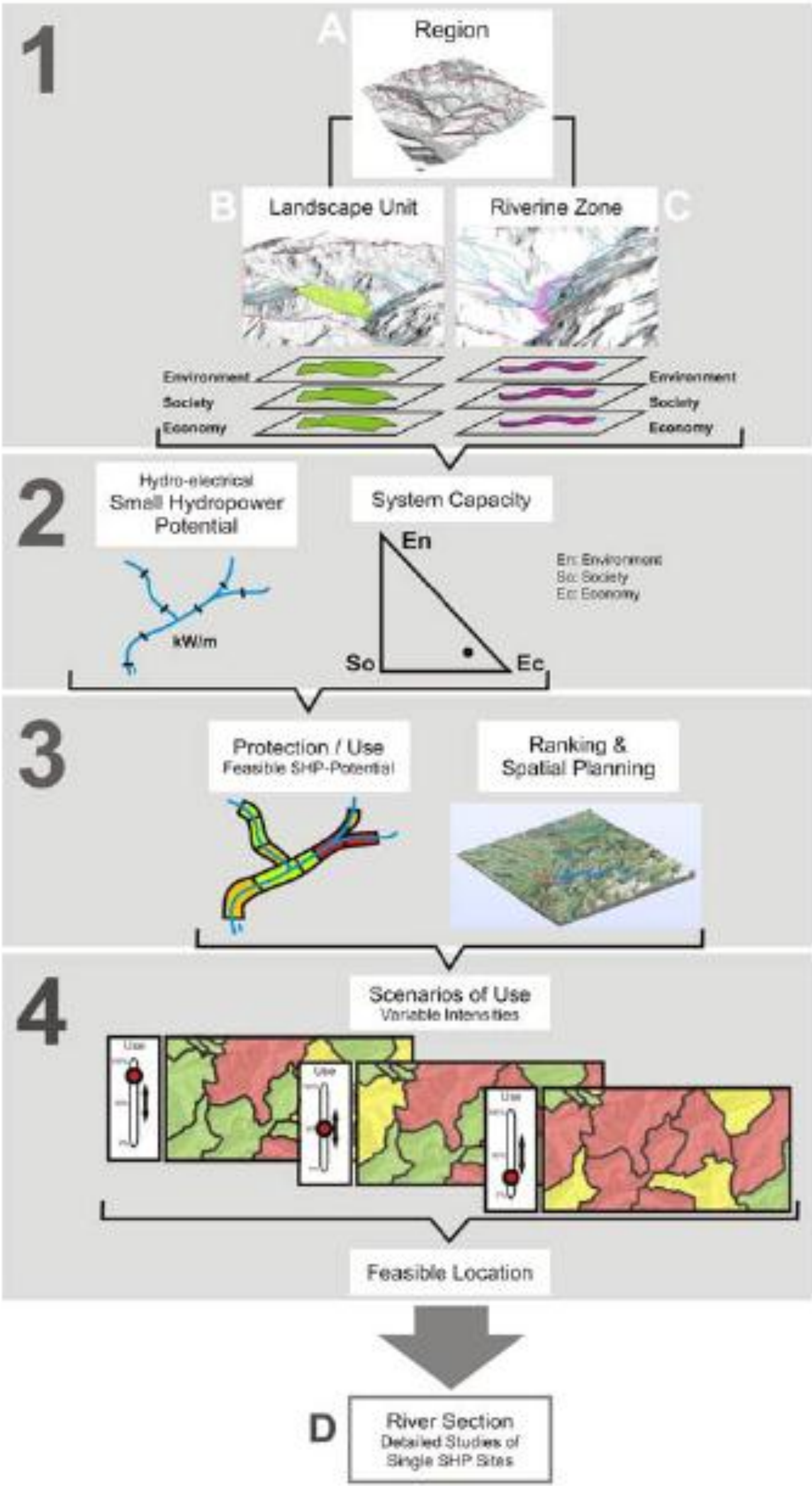
Source: Adjusted from https://www.guarantee-of-origin.ch/reports%5CDownloads%5Cwarteliste_DE.pdf

The following observations can be derived from Table 4-13. Firstly, the number of plants forecasted to be built taking into account the adjustment factors is about an increase of 31% compared to the number of plants in operation in 2010 (see Table 4-9). Secondly, the forecasted additional installed capacity of 294 MW is an increase of about 34% compared to the installed capacity in 2010. The average installed capacity per plant is thus in the same range as the existing plants. Finally, thanks to the FIR, the additional forecasted production of 1’178 GWh and the new production in 2011 of 163 GWh (see difference between Table 4-11 and Table 4-12) account together for 1’341 GWh. This is within the upper range of the expected additional production of the evaluations above till 2035 compared to 2010 (+1’100 to 1’300 GWh). This shows that the estimations for 2035 can be reached and might even be exceeded.

The massive deployment of SHP projects thanks to the FIR led to the need to develop methodologies for the authorities to assess not only individual projects, but the regional development of SHP as well. Spatial planning and the right balance between hydropower use and environmental protection on a regional scope got into the focus of the authorities. In some regions, the law forbids the construction of SHP plants. In others, the environment is suitable for the SHP development such as in industrial zones, in already canalised river sections, as touristic attractions, in river sections with high theoretical potential for SHP with low ecological value, etc. However, the development of SHP is not a simple question of ‘yes’ or ‘no’, but rather an overlapping of different potentials with individual claims of protection or use.

Such a methodology was first attempted in the Canton of Bern (Wehse, 2009) and led to the Cantonal water use strategy (AWA, 2010). At the Federal level, a similar approach has been taken to deliver recommendations on the formulation of Cantonal water use and protection strategies related to SHP (BAFU, BFE et al., 2011). More on the latter document will be developed in Section 5.2.

The research of Hemund at the University of Bern develops a more detailed methodology (Hemund and Weingartner, 2012). It is part of the Federal research program “Hydropower” and aims at evaluating the SHP potential in Switzerland based on a holistic approach. The methodology considers ecological, social and economic aspects, as well as regional water management and spatial planning. The research question is: Are there any possibilities for an increase in SHP production within a specific region considering both the hydropower potential and the need for protection? The assessment takes into account observations on four different spatial units, i.e., region, landscape unit, riverine zone, river section. The technical data on the technical hydropower potential, coming from the other research project with WaterGisWeb mentioned above, are combined with ecological, economic and social considerations to evaluate the expected SHP potential of a region. Figure 4-12 shows the workflow of the suggested methodology. It is outlined in four steps and the “*skeletal structure is based on simple assessment scales which lead to a final assumption whether a river section is suitable for intensified* *use or should rather be protected. Overall, the method is accomplished, as mentioned above, on different observation levels (A to D)"* (Hemund, 2010). The methodology is developed for the Cantonal authorities to help them to develop water use and protection strategies. Final results will be available in mid-2012.



Source: (Hemund, 2010)

Figure 4-12: Workflow for the integrated evaluation of the SHP potential

In the coming decades, the hydropower potential, including SHP, will be affected by two factors. Firstly, global warming and climate change are very likely to impact the production of hydropower by changing water flow. There are currently no figures available related to SHP. The latest study on the topic (Schweizerische Gesellschaft für Hydrologie und Limnologie SGHL, 2011) shows that rainfall will increase on the northern part of the Alps, whereas it will decrease on the southern part mainly during the summer. The frequency and intensity of heavy rainfall is going to increase as well. Melting glaciers will lead to additional hydropower production during the coming decades, but by 2100 most of the glaciers will have melted. The forecast for hydropower production in 2050 is a slight increase of about 0.3 to 0.7 TWh. However, financial investments are required to enable this increase dealing with sedimentation problems and natural risks. Climate change is thus likely to affect only marginally SHP production by 2050.

Within a shorter horizon, the Energy Perspectives 2035 evaluated that the water runoff will decrease by 7% until 2035 compared to 2000 (BFE, 2007c: 35). The precipitation in winter (December-February) will increase by 6%, in summer (June-August) decrease by 8% and in autumn there will likely be a decrease as well. The forecast for spring is unclear. These changes will affect both storage and run-of-the-river plants, and will require more storage capacity to transfer water between the seasons in order to secure water for the different uses throughout the year.

Secondly, the regulation on minimum residual flows (see Section 5.2.2) will affect each new negotiation for the water use and especially the renegotiation at the end of term of currently on-going water concessions. Again, there are no estimates for SHP, but for hydropower in general, the loss in production is between 900 (until 2035) and 1’800 GWh a year (in 2050) compared to 2004[75]. However, with the exception rule for streams above 1’700 meters above sea 50 GWh could be regained[76]. The maximum production loss by 2070 would be 2’000 GWh[77]. These figures, as well as the one related to climate change, have to be taken with considerable caution as the uncertainties in their evaluation remain significant.

A factor increasing the SHP potential is the rehabilitation of abandoned and poorly maintained SHP plants, which is well encouraged (BAFU, BFE et al., 2011). The rehabilitation of existing plants often leads to an increase in production thanks to more efficient electromechanical equipment such as the turbines and generators. The gain gets bigger with the age of the equipment. However, in case of a renewed water concession the gain can be lost or worse, the production decreased. The potential for all hydropower rehabilitation has been evaluated at 2’100 GWh a year compared to 2000 (BFE, 2008c). However, the application of the new regulation on the minimum residual flows may reduce mostly this gain. Nevertheless, rehabilitation contributes to the safeguard of the heritage within the landscape and can in certain cases significantly improve the environmental situation around the plant (e.g., fish-bypass, stabilisation of the river banks, etc.). The decision between rehabilitation or a new plant depends on the economic evaluation as well as the remaining water rights. In some cases, a new plant could be the better option.

At the end of 2010, of the 190 projects in operation with the FIR, 38% were expanded or renovated plants and most of them were on streams and not within infrastructures. They produced 64 GWh a year. Within the remaining announced FIR projects, about 20% are expanded or renovated plants (Manser, 2011). Furthermore, a survey among the Cantons showed that the rehabilitation of SHP plants can lead to production gains of a few per cents[78]. There is therefore remaining potential with rehabilitation projects, which is already accounted for in the above potential evaluations.

[75] http://www.parlament.ch/D/Suche/Seiten/geschaefte.aspx?gesch_id=20103220 (accessed on 04.11.2011)
[76] http://www.admin.ch/ch/d/sr/814_20/a32.html (accessed on 04.11.2011)
[77] http://www.parlament.ch/D/Suche/Seiten/geschaefte.aspx?gesch_id=20103220 (accessed on 04.11.2011)
[78] Workshop “Energiestrategie 2050: Wasserkraftpotenzial der Schweiz”, Bern, 15.11.2011.

Table 4-14 summarises the different potential evaluations. To recall, the policy SHP target of additional 1'100 GWh in 2030 compared to 2000 represents about 4.4 TWh SHP production in 2030 (BFE, 2008c). This target will clearly be met and exceeded. Forecasts with current FIR projects, the production in 2010 and the additional production thanks to FIR in 2011 lead to an estimated expected potential of 5.1 TWh. Additional projects in the coming years have to be taken into account as well to estimate the potential in 2030 (e.g., very low-head schemes, storage SHP). Climate change will not significantly change the production by 2050. Residual flow regulation will also not change significantly the production as explained above. Thus, the expected potential of SHP in 2035 is likely to be slightly above 5 TWh and thus exceed the SFOE (2007) and EnergieTrialogSchweiz evaluations. By 2050 and with the adequate institutional framework, an additional potential of some of some hundreds GWh could be tapped reaching between 5.2 and 5.6 TWh, which is about an increase of about 40-50% compared to 2010.

Table 4-14: Overview of the different expected SHP potential evaluations (in order of appearance)

Reference year: 2010, otherwise mentioned	(no year)	2035	2050	Source
Desserich and Funk	Technical pot. of 9.0 TWh (+139%)			(Desserich and Funk, 1987)
SFOE, Energy strategy 2050			+1.9 TWh, for a total of 5.7 TWh (+51%), reviewed estimate +1.2 TWh, for a total of 5.1 TWh[1] (+35%)	(BFE, 2011a)
SFOE, Energy perspective 2035		+1.5 TWh[2], for a total of 4.9 TWh (+30%)		(BFE, 2007b)
EnergieTrialogSchweiz		+1.2 TWh for a total of 5 TWh (+33%)		(Energie Trialog Schweiz, 2009)
PSI		Technical pot. of 5.6–6.8 TWh (+49–80%)		(PSI, 2005)
WWF (FIR projects)	+1.1 TWh (+29%)			(Ernst Basler + Partner, 2010)
Evaluation based on FIR projects	+1.3 TWh (+35%)			Table 4-11, Table 4-12, Table 4-13

[1] *With an improved institutional framework, the estimate is +1.7 TWh (+49%)*

[2] *Compared to 2003*

Sources: in the table

4.2.3 The state of SHP in the Canton of Valais

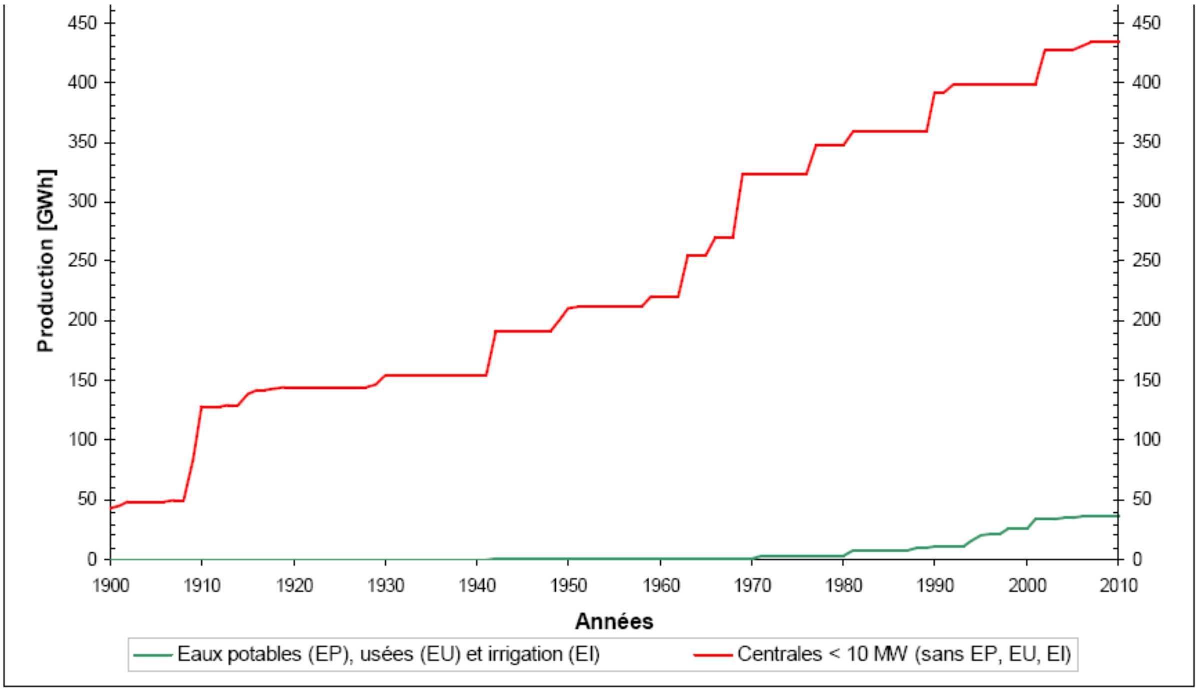
Today's plants are given in Table 4-15 in categories by installed capacity. The multipurpose plants contribute to a significant amount of the electricity production from MHP plants. In 2010 for example, 16 GWh were produced by plants on the drinking water network[79]. SHP represents 5.4% of the hydropower production in the Canton, compared to 10.1% for the Swiss average. This comes from the fact that the Canton of Valais has proportionally more large plants.

Table 4-15: Hydropower in the Canton of Valais, excluding inter-Cantonal and international plants

Category	Number of plants	Installed capacity [MW]	Expected production for 2011 [GWh]	% of hydropower production of Valais
Below 300 kW	41	5	26	0.3%
300-1'000 kW	28	17	59	0.6%
1'001-10'000 kW	27	110	424	4.5%
Below 10 MW	**96**	**132**	**509**	**5.4%**
Above 10 MW	**39**	**4'364**	**8'869**	**94.6%**

Sources: (BFE, 2011g) and Service de l'énergie et des forces hydrauliques, Canton of Valais, 2011

Historically, the SHP production evolved as shown in Figure 4-13. SHP had a constant growth and multipurpose plants began to emerge in the 1970s. The list of all SHP plants operating in 2010 can be found in Appendix L.1. A Cantonal website shows on a map all the hydropower plants for the Valais[80]. For each plant general information (e.g., owner, first year of operation) and technical characteristics (e.g., installed capacity, production) are given.



Legend: Eaux potables (EP) = drinking water; eaux uses (EU) = waste water; eaux irrigation (EI) = irrigation water

Source: (Conseil d'Etat du Canton du Valais, 2008)

Figure 4-13: SHP production in the Canton of Valais during since 1900

[79] Personal communication with Service de l'énergie et des forces hydrauliques, Canton of Valais, 24.10.2011.
[80] http://www.vs.ch/Navig/navig.asp?MenuID=16458 (accessed on 15.08.2011)

At the beginning of 2011, there was a further 60 MHP and SHP projects on the FIR waiting list representing an additional 42 MW and 154 GWh[81][82]. Compared to 2010 (see Table 4-15), this shows an important remaining potential. Within the on-going evaluation of the Swiss hydropower potential by the SFOE, the Canton of Valais has a forecasted additional SHP production between 150 and 300 GWh[83]. Estimates from the Canton dating back to 2008 evaluated that the SHP production could be increased to about 930 GWh/year till 2035 (Staatrat des Kantons Wallis, 2008: 40).

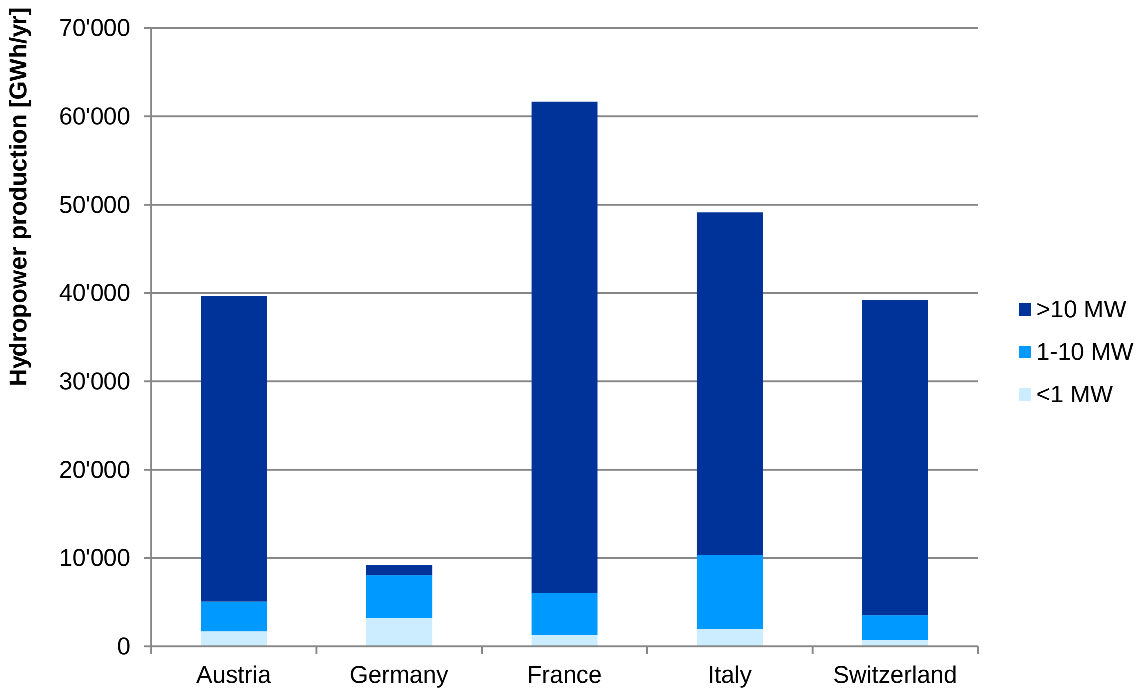
The hydropower potential within Communes was studied in 2007-2008 within the Blueark Program[84]. The focus was on multipurpose infrastructures. 41 projects on drinking water networks were identified which could produce about 20.5 GWh/year, and four projects on waste water networks with a production potential of about 2.8 GWh/year. Some of these projects were further developed and applied to receive the FIR. The Blueark Program still facilitates the use of drinking water networks for MHP and SHP schemes and can support Communes in the identification of such projects.

Hydropower has a major significance for the economy and the development of the Canton of Valais. Within the current developments in the electricity market, the opportunities for new pumped-storage plants and SHP plants are very much present in the Canton. Securing and creating new jobs within the Canton is a goal facilitated by the Cantonal government among others with the program The Ark[85]. This program concerns hydropower, including SHP development, and financed the Blueark program. For example, some loans without interest can be obtained. Furthermore, SHP can be promoted as a local “product” providing local electricity and local jobs.

4.2.4 SHP in Europe and worldwide

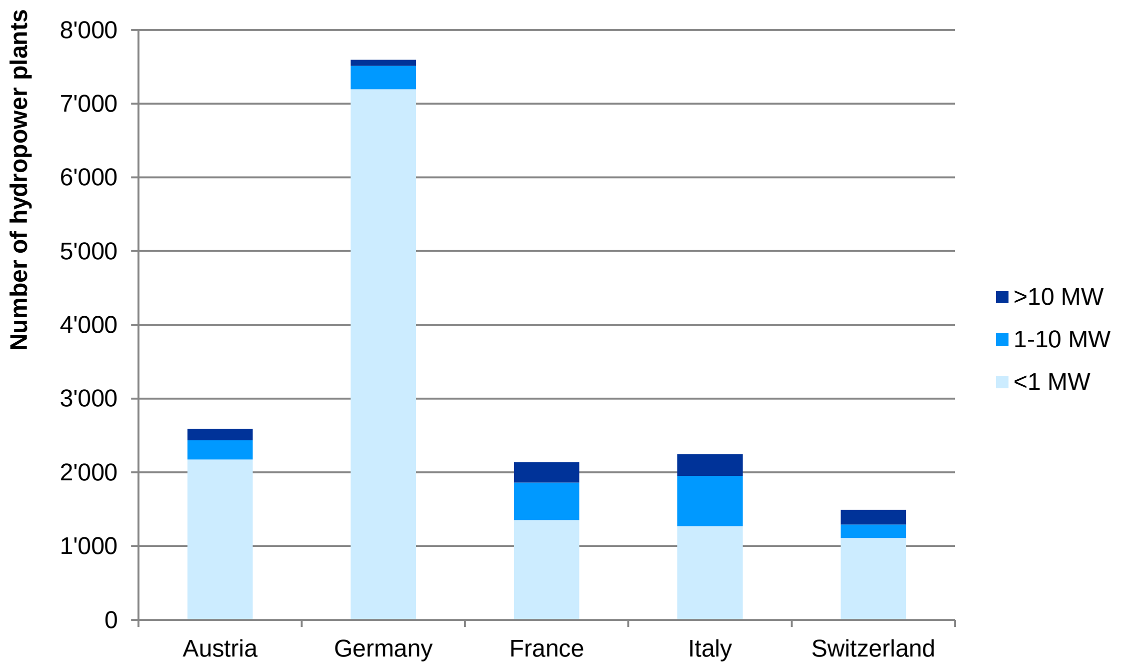
SHP has a significant role in the neighbouring countries. Figure 4-14 and Figure 4-15 compare the hydropower sector in these countries with Switzerland. The SHP production is similar in Austria, France and Switzerland. Italy produces about three times the Swiss SHP production and Germany about twice even though it has about six times the number of plants compared to Switzerland. France and Italy have about the same number of MHP plants, but clearly more SHP plants. Austria has more MHP plants, but a similar number of SHP plants.

[81] http://www.stiftung-kev.ch/berichte/anmeldestatistiken.html (accessed 15.08.2011): Statistics for 2010
[82] More information on the FIR SHP projects per Canton can be found at the FIR foundation (http://www.stiftung-kev.ch/berichte/2010.html).
[83] Presentation of the results of the survey “Wasserkraftpotenzial der Schweiz”, SFOE, Ittigen, 14.02.2012.
[84] http://isi.hevs.ch/valais/etudes-potentiel-hydroelectrique.html (accessed on 15.08.2011)
[85] www.theark.ch



Sources: HYDI Database (http://www.streammap.esha.be/6.0.html) and (Leutwiler, 2008; BFE, 2010b)

Figure 4-14: Hydropower production in neighbouring countries by installed capacities in 2009



Sources: HYDI Database (http://www.streammap.esha.be/6.0.html) and (Leutwiler, 2008; BFE, 2010b)

Figure 4-15: Hydropower plants in neighbouring countries by installed capacity categories in 2009

The umbrella organisation of SHP in Europe, the European Small Hydropower Association (ESHA), which includes Swiss members, takes an active role in promoting SHP within the RET facilitation schemes in the EU. ESHA publishes yearly updated figures on the SHP current situation (capacity, production, number of plants), forecast and potential within the HYDI database[86]. The database includes market data concerning employment and companies' figures in the hydropower sector, as well as average investment costs per MW and average production costs. Furthermore, policy data deals with the policy instruments, the legislation and the concession procedures. It therefore concerns the institutional frameworks. The figures are for the individual EU-27 countries.

On the EU level, most on-going research and publications are also done by the ESHA. One of the main research activities is currently dealing with the challenges of the implementation of the EU Water Framework Directives together with the EU RES-e directives and the 20-20-20 EU goals, which include the facilitation of SHP. An example is the report entitled "HYDRorPOWER?" (APER and ESHA, 2009).

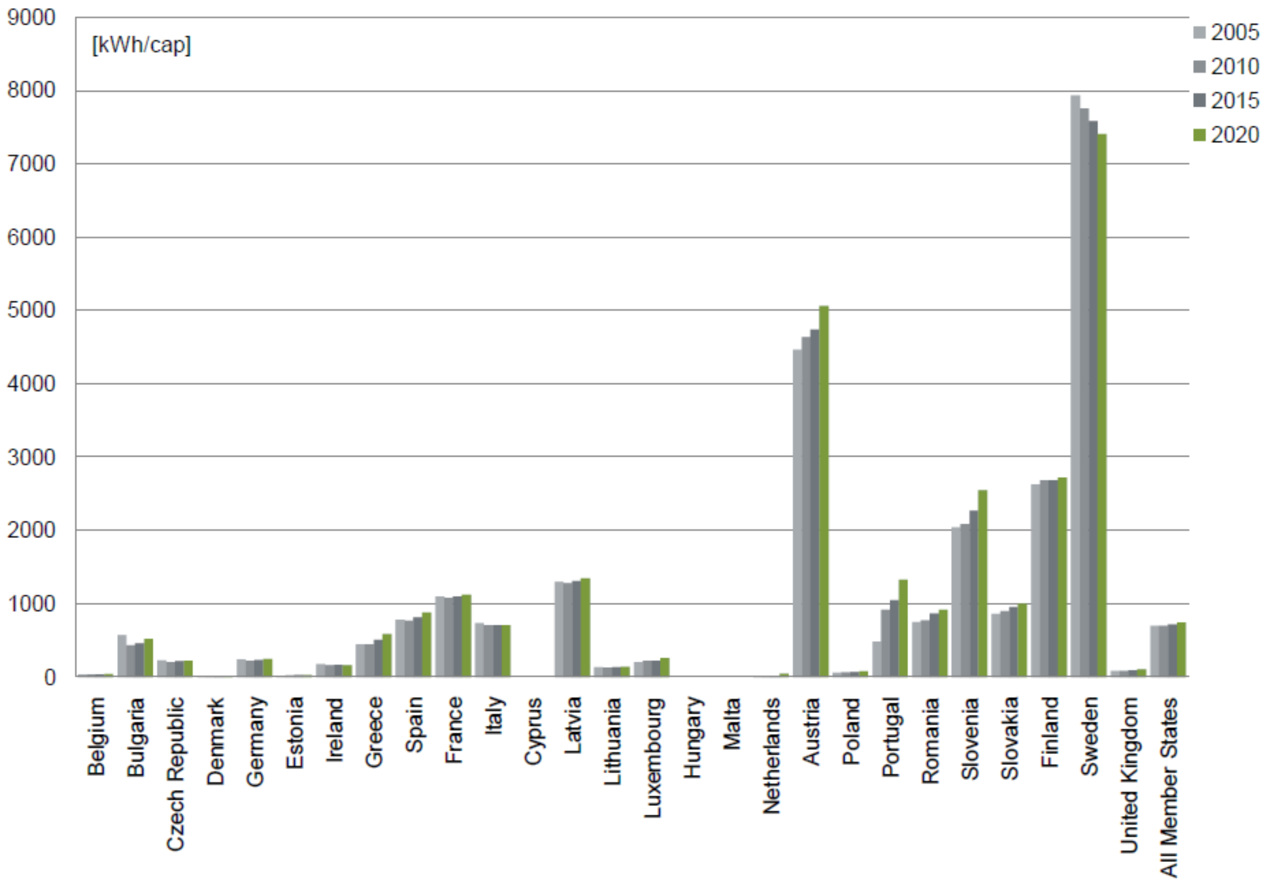
In 2010, over 21'000 SHP plants were in operation in the EU-27 with a total installed capacity of over 13'000 MW and a production about 41'000 GWh/year. 90% of the installed capacity was concentrated in six members states – Italy (21%), France (17.5%), Spain (15.5%), Germany (14%), Austria (9.4%) and Sweden (7.7%) (Platform Water Management in the Alps, 2011b). The largest capacities in the new member states are in Bulgaria, the Czech Republic, Poland and Romania (ESHA, 2011). SHP has a great importance in Norway as well.

The additional economic feasible potential for SHP in EU-27, both from upgrading and from new plants, is considerable accounting up to 10'000 MW and 38'000 GWh annually (ESHA, 2011). This potential takes into account the environmental constraints. The largest potentials are in Austria, France, Italy, Poland and Romania. Non-EU members Norway and Turkey have a large additional potential as well.

However, in certain countries with large potential, SHP faces major opposition and institutional barriers. SHP can even be excluded from programs designed to assist RET development (SHAPES, Mhylab et al., 2010). In Romania a moratorium on new SHP plants was in consideration, and in Slovenia a new regulation on residual flow decreases the financial viability of new SHP significantly (ESHA, 2011).

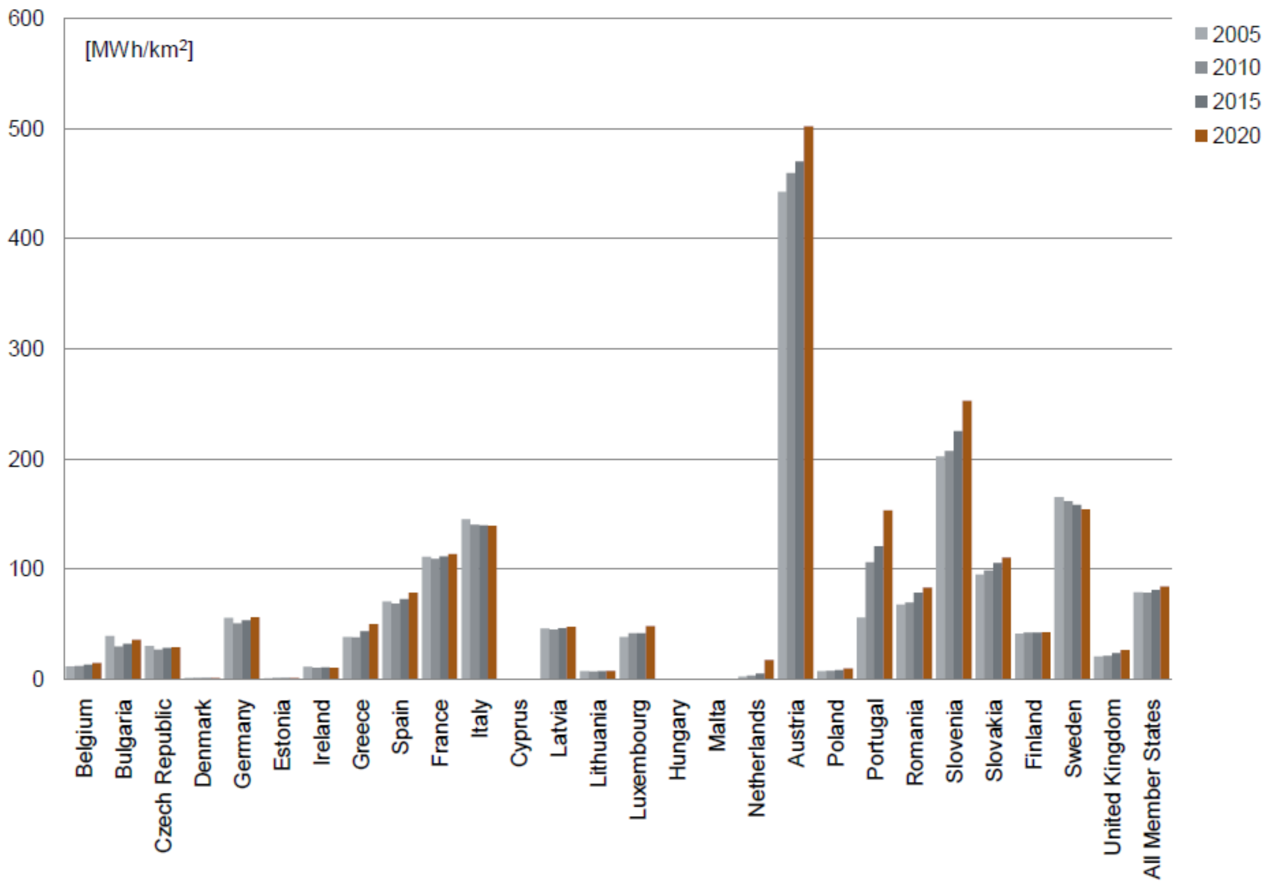
The National Renewable Actions Plans of the European Member States summarises the SHP situation in 2005 and 2010 and offers forecasts for 2015 and 2020. An overview can be found in Beurskens and Hekkenberg (2010). Figure 4-16 and Figure 4-17 show the hydropower production related to the capita and surface area of the EU-27 countries. Austria clearly has the lead. Sweden also has very strong figures for hydropower production per capita. The hydropower production per surface is, besides Austria, significant for France, Italy, Portugal, Slovakia, Slovenia, Spain and Sweden. In the case of Sweden, the hydropower production is decreasing. Other countries have minor increases, except Austria, Portugal and Slovenia for which the increase is significant.

[86] http://www.streammap.esha.be/18.0.html (accessed on 04.11.2011)



Source: (Beurskens and Hekkenberg, 2010)

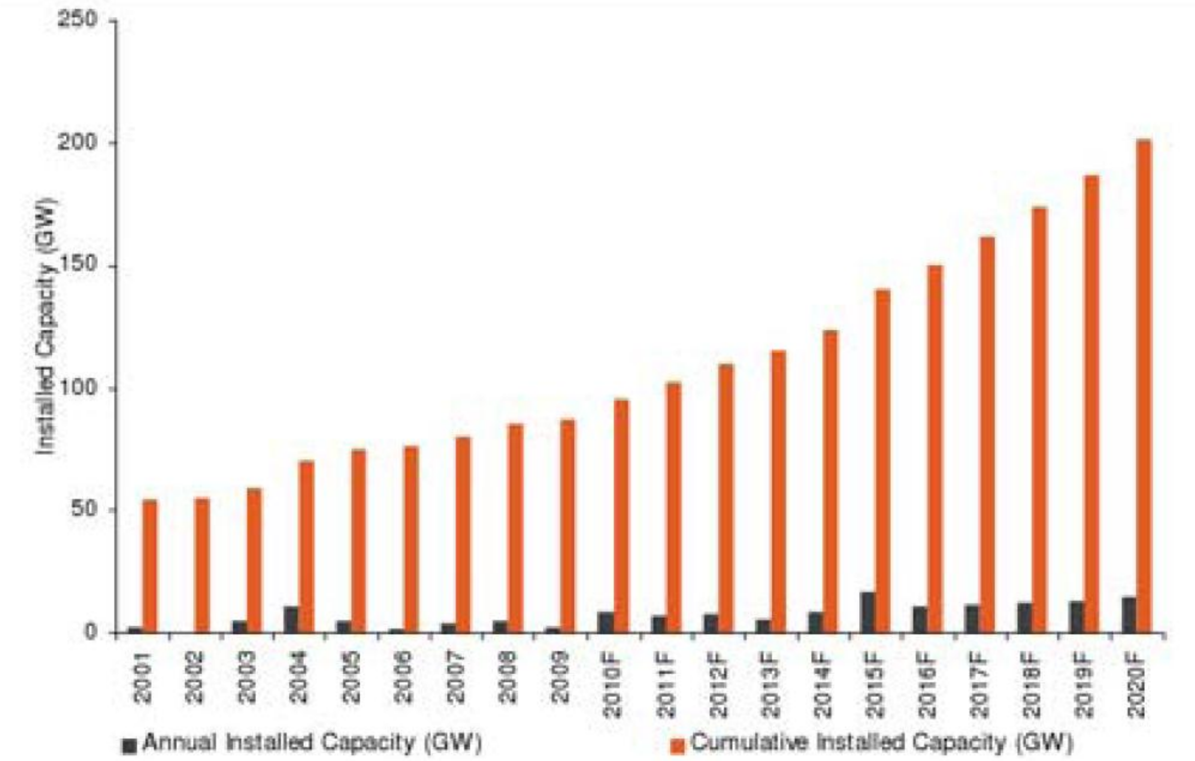
Figure 4-16: Calculated per capita (2008) electricity production for total hydropower for the period 2005-2020



Source: (Beurskens and Hekkenberg, 2010)

Figure 4-17: Calculated per surface area (2004) electricity production for total hydropower for the period 2005-2020

Small hydropower increased to an estimated 85 GW worldwide in 2009. Most of the capacity is installed in Asia. In China, the boom in SHP has continued with 4–6 GW added annually during 2004–2008 (Martinot, Sawin et al., 2009). SHP as well as MHP has a huge remaining potential in several African and Asian countries. Figure 4-18 shows the potential SHP development till 2020.



Source: (Rolland, 2011)

Figure 4-18: Historical and forecast annual and cumulative installed capacity (GW) for SHP from 2001 to 2020

The growth of the world's population and of GDP, especially in developing countries, will require the appropriate infrastructures for water and electricity supply, irrigation, flood protection, productive fishery, industries and services. The addition of SHP in multipurpose infrastructures is economically sensible and has no major negative environmental or social impacts as developed above. Instead, it has a broad range of benefits through ensuring distributed energy supplies, additional revenues for the local population (prevention of migration into cities), and can benefit from CO_2 compensation instruments (Clean Development Mechanisms (CDM), Adaptation Funds).

SHP is one of the most cost-effective energy technologies for rural electrification in developing countries. It is a main energy source for distributed and off-grid electricity production. Huge investments for establishing transmission grids are avoided. Its role has to be emphasized in developing local economy, securing livelihoods and contributing to social infrastructure in developing countries.

SHP plants have the most chance of being economically viable if they provide power to productive end-users (e.g., mill, local manufacturer) during the day, and if they are socially accepted at night (e.g., fulfil a role within social infrastructure such as public lighting), which is considered in the same way as a safe water supply, school or health program.

For Swiss companies working on SHP (e.g., manufacturer, engineering company, etc.) the potential in developing countries offers significant export opportunities. As the amount of projects to be further implemented in Switzerland is limited and in order to keep the know-how and knowledge, SHP projects in other countries can be developed. The institutional frameworks need to have certain stability before investing in such projects. However, there are clearly more opportunities to come and further investigations are needed.

Conclusion

Small hydropower is a well developed technology. However, there is still significant need for R&D and innovation to make up for un-systematic R&D, cost reduction and better environmental integration. Furthermore, SHP is a complex technology involving multiple disciplines. Among the RETs, SHP has one of the highest energy payback ratios and belongs to the most energy efficient technologies. The production costs are in average lower than for other RETs. However, SHP has high investment costs which are driven by over 50% by the civil works.

With the newly introduced FIR, SHP will further develop in Switzerland. The available technical potential which became an economic potential thanks to the FIR might be built if the environmental integration can be guaranteed and social acceptance increased again. Compared to 2010, the electricity production from SHP can increase by about 37% until 2035 to reach slightly more than 5 TWh in yearly production. The main threat for the SHP development is the opposition because of its environmental impact. Opportunities for SHP are the development of multipurpose schemes with the convergence of several sectors, such as artificial snow making, irrigation and drinking water, and the storage and pumped-storage schemes. The latter is an example of SHP technology having to continue to evolve within the perspective of the co-evolution between institutions and technologies in the electricity sector as developed later in Chapter 7. Beforehand, the institutional framework of SHP is described and analysed.

5. The institutional framework of small hydropower and the stakeholders in Switzerland

Without institutional frameworks which facilitate renewable energy technologies (RETs), the diffusion of RETs would only occur in a few niche markets. Institutional facilitation is justified as a way of correcting negative externalities in the liberalised electricity market and enabling dynamic efficiency in the development of the RET (Menanteau, Finon et al., 2003). The negative environmental externalities are being increasingly internalised in the electricity production costs (e.g., CO_2 compensation schemes for fossil fuels). Efficiency is increased by the adoption of the technologies. To reach a sustainable electricity supply RETs have to be further developed and specifically facilitated by setting the right institutional frameworks depending on their level of maturity. These frameworks need to be stable to reduce uncertainty and ensure long-term investment continuity[87] (Haas, Panzer et al., 2011).

This Chapter starts by identifying the small hydropower (SHP) stakeholders in Switzerland followed by looking at the existing institutional framework affecting SHP. The main policy instruments concerning SHP are identified.

5.1 The SHP stakeholders in Switzerland

This Section introduces the stakeholders who design, construct and operate SHP plants, as well as the stakeholders involved in shaping the institutions affecting SHP. The Section contributes to the understanding of the co-evolution between institutions and the SHP technology by describing the different role of the various stakeholders (i.e. the actors within the coherence framework).

The stakeholders of SHP in Switzerland are manifold and very heterogeneous regarding their background and know-how. They have different agendas and put diverse pressures and expectations on the use of the water resource for SHP. The main conflicting expectation is between the stakeholders wanting to increase the electricity production from SHP, and the stakeholders wanting to protect the environment, including the naturalisation of sites in use for SHP. These expectations lead to pressures on politics. Both expectations are partly driven by existing legislation (see Section 5.2.1). Climate and RET targets add pressure to exploit the SHP potential, whereas environmental policies demand conservation. Even within the public administration, there are conflicting views on the SHP development (e.g. between the Swiss Federal Office of Energy (SFOE) and the Federal Office for the Environment (FOEN)). Furthermore, the local and national public perspective is not necessarily aligned. Local stakeholders might oppose a SHP project because of its environmental impact, whereas national stakeholders aiming to reach RET targets might promote the same project. Finally, the media influences the debate between exploitation and conservation by reporting on concrete projects.

With the introduction of the feed-in remuneration (FIR), new stakeholders who design and construct SHP plants came on the market. Some stakeholders have the technical competencies, whereas others not which leads to poor development (called DYI work), especially in the case of MHP[88]. Big companies, such as Andritz for

[87] Especially in the case of SHP with plant's lifetime of several decades, the financial evaluation is conducted over 10 to 30 years, thus the necessity of stable institutional frameworks.
[88] Interview CH-6

turbines[89], started to invest into SHP as well which improves the quality within the SHP development. According to the director of Mhylab[90], there are around four SHP turbine suppliers in Switzerland and around 30 across Europe.

The main SHP stakeholders can be categorised as shown in Table 5-1. For certain categories some stakeholder names are given. The Table has been obtained through the literature review and documents study (e.g., real projects, reports of research programs, online research), interviews and participatory research.

Table 5-1: SHP stakeholders in Switzerland (in italic public entities)

Category	Sub-category	Name (not exclusive)	Comment
SHP electricity producer	National electricity production company (including its subsidiary company)	Alpiq (incl. Alpiq EcoPower Schweiz AG), Axpo (incl. Elaqua), BKW (incl. Sol-E), CKW, EGL, Repower, Groupe E (incl. Green-watt), Romande Energie (incl. Romande Energie Renouvelable)	These firms aim to increase the part of RETs in their production mix.
	Small producer	ADEV, Hydroelectra, entegra, Communes (e.g., SI Bagnes, Gemeindeverband Blattenheid)	Local initiatives and passionate entrepreneurs
SHP equipment and construction company	Swiss company	See “Marktführer” in the Appendix L.2 or online[1]: - Civil work - Turbines - Pipes - Electric equipment	
	International electromechanical supplier	Alstom Power Hydro, VA Tech Hydro/Andritz, Voith Siemens Hydro, GE Energy, THEE (France, for MHP)	
	Contractor	Local civil works companies	
SHP researcher and designer	Engineer office	entec, ITECO, STUCKY, BG, some in the “Marktführer”[1] (e.g., Ryser, IM Maggia)	For the design and engineering
	SHP potential evaluation	WaterGisWeb	Evaluates the technical potential of SHP in Switzerland. Mandate by SFOE.
	Research laboratory	Mhylab	Turbine research
	University	*EPFL, ETHZ, EAWAG, HES-SO, University of Bern, Hochschule Luzern*	
NGO	Environmental NGO	ProNatura, WWF, Rheinaubund, Greina Foundation, Greenpeace	Key NGOs for environmental protection
	Fishery association	Swiss Fishery Federation (and its local entities) and Swiss Professional Fishery Association	Protection of the fishes

[89] E.g. http://www.andritz.com/ANONID278CB92E709C660/hydro/oohm-hydro-products-service-2/hydro-products-and-services-large-hydro/hydro-products-and-services-large-hydro-hydromatrix/hydro-products-and-services-large-hydro-hydromatrix-straflomatrix.htm (accessed on 26.10.201)
[90] Visite of the Mhylab laboratory, 02.11.2010

	SHP umbrella association	ISKB / ADUR	Represents the SHP industry in Switzerland
	Electricity and Water umbrella association	VSE, SWV, SVGW	
	Renewable and ecological electricity production	Energie plus!, ADEV, ADER	Promote ecological and distributed RETs
	Green electricity marketing	Naturemade – VUE, TÜV	Label for ecological electricity
	Cleantech organisation	CleantechAlps	Promotes amongst others SHP
	Other	Revita Foundation	Aims to maintain and revive SHP
	Other	WasserAgenda 21	Coordination platform around water and hydropower for Switzerland
	Other	Netzwerk Wasser in Berggebiet	Coordination platform around water and hydropower in the Alps
	Other	Association Suisse pour l'aménagement des eaux	NGO for the water sector
Legislator	*Federal level*	*Federal parliament*	
	Cantonal level	*Cantonal parliament*	
	Communal level	*Commune legislative body*	
Government and public administration	*Federal level*	*Federal Council and* *Federal administration:* - *SFOE* - *FOEN* - *ARE*	
	Cantonal level	*Cantonal government and administration*	*E.g. in charge of water rights*
		Conference of the Cantonal energy directors	*Most important entity for the collaboration between the Federal State and the Cantons in the energy sector. Cantons with major interest in SHP can introduce their requirement through this organisation.*
	Communal level	*Communal government and administration*	
Regulator	*Independent regulatory authority in the electricity sector*	*ElCom*	*Judicial authority on disputes relating to network access and payment of the FIR (see Section 5.2.2).*
Banks	Cantonal bank	BEKB, BCV, BCVs, ZKB, etc.	Lender or investor
	Local bank	Raiffeisen Bank, Alternative Bank	Lender or investor
Media	Public national television and radio	SF/DRS, TSR/RSR, RSI	Report for example on innovation (e.g.

			Wasserwirbelkraftwerk[2]) and disputed SHP projects (e.g. in Oberwallis).
	Newspaper		
Insurance	National company	National, Mobiliar	Insurance during construction[3] and during operation[4]
Landowner	Private person		
Customer	All pay FIR contribution		
	Customer buying labelled green electricity from SHP		Cities, companies or private persons
Transmission System Operator (TSO)		Swissgrid	The grid has to have the capacities to integrate the SHP plants.
Other		Energiepool	Manages the fund for the FIR
		Platform Water Management in the Alps (part of the Alpine Convention)	Platform for the SHP development respectful with environment in the Alps

[1] *http://www.iskb.ch/marktfuehrer-kleinkraftwerke/ (accessed on 26.10.2011)*

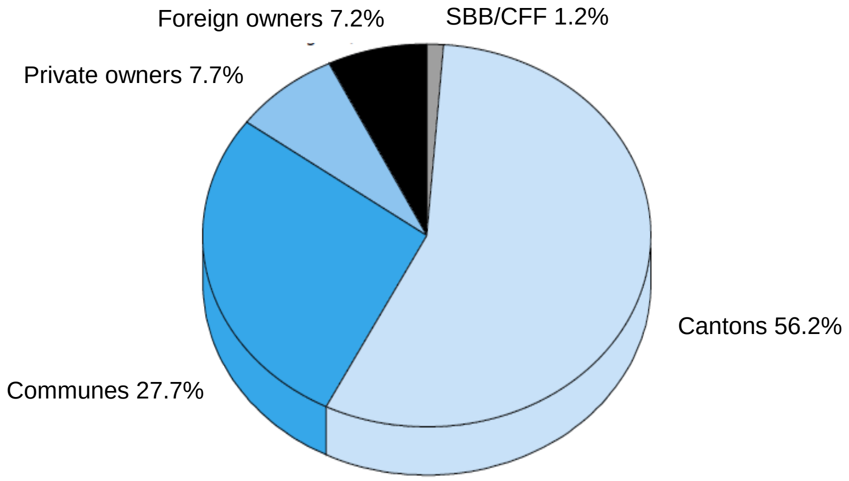
[2] *http://www.videoportal.sf.tv/video?id=3839c546-9608-4f44-bd3b-e0ce1aef8450 (accessed on 03.02.2012)*

[3] *Contract works insurance, liability insurance*

[4] *Operational liability insurance, operating loss insurance, water damage insurance*

For a much larger stakeholders list concerning the whole Swiss water sector, a detailed table can be found in Zysset et al. (2007, Table 3). Current trends such as global warming leading to additional artificial snow making infrastructures in touristic regions or additional drinking water needs due to the demographic growth will bring further pressures on the water sector. SHP will have to develop within these pressures and may be able to exploit them as opportunities, i.e. combine SHP with the additional needed infrastructures for drinking water distribution and artificial snow making (see Table 7-3).

It has to be highlighted that many hydropower plants have been constructed as so-called partner plants. Several electricity producers joined together to design, construct and operate the plants. Often the partnerships involved Communes as well, especially for SHP plants. In the case of small SHP and MHP, the plants can also be owned by a private person, a SME and/or the Commune alone. The following figure summarises the type of owners and their importance for all power plants in Switzerland. 85% of the plants are publically owned.



Source: (BFE, 2011d: 47)

Figure 5-1: Origin of the equity of electricity plants in Switzerland, 5.1 billion CHF (2009)

5.2 The institutional framework of SHP

The institutional framework of SHP in Switzerland is very complex. It is not only determined by cross-sectorial regulation (e.g., water and energy sector, spatial planning and environment), but also by a multi-level legislation between the Federal State, the Cantons and the Communes. Some administrative procedures are completed at the Federal level (e.g., feed-in remuneration allocation), others at the Cantonal level (e.g., water concession granting) and finally some at the Commune level (e.g., construction permission). Finally, the institutional framework evolves with the main institutional changes in the electricity sector such as the liberalisation and the facilitation of RETs (see Section 2.2).

This Section describes the institutional framework of SHP in Switzerland and also in the Canton of Valais as this Canton has been used as sub-unit of analysis (see Section 1.5). The Section introduced the legislation relating to SHP, as well as the main policy instruments deriving from it. It also includes instruments based on private initiatives such as labelled green electricity. Looking beyond Switzerland, policy instruments used in neighbouring countries and the literature are introduced in order to present alternatives for the analysis in Chapter 6.

5.2.1 Legislation relating to SHP in Switzerland

Several articles of the Swiss Constitution relate to SHP[91], whereby the most important one is Article 76. It allocates the sovereignty over water to the Cantons. However, the Federal government keeps the authority to stipulate the principles for the use of the water and for the environmental protection. The Federal administration is in charge of dam safety, but delegates this role to the Cantons for small dams (see Section 5.2.3)[92].

The second most important article is Art. 89. In Alignment 2, it states that the Federal government is in charge of setting the general guidelines on the use of domestic and renewable energy sources. This concerns also SHP.

The main Federal laws and ordinances are given in Table 5-2.

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[91] E.g., Articles 50, 73, 74, 75, 76, 78, 79 and 89: http://www.admin.ch/ch/d/sr/101/index.html (accessed on 26.10.2011)

[92] More information also under: http://www.bfe.admin.ch/themen/00490/00491/00494/index.html?lang=en (accessed on 26.10.2011)

Table 5-2: Swiss laws and ordinances relating to SHP

Domain	Name (Year)	SR Number	Description
Energy	Energy Law (1998) Energy Ordinance (1998)	730.0 730.01	Enable the program "Swiss Energy" and define the feed-in remuneration (see Section 5.2.2).
CO_2	CO_2 Law (1999) CO_2 compensation Ordinance (2010)	641.71 641.713	Regulate CO_2 compensation. Art 11c of the Law relates to RETs, whereby currently only biomass plants generating electricity can generate CO_2 credits. Thus SHP is not included. (See Section 6.6.) The Ordinance regulates specificities linked to gas-fired plants.
Electricity	Electricity Supply Law (2007) Electricity Supply Ordinance (2008)	734.7 734.71	Regulate grid access and the "balance group renewable energies" (see Section 8.2.1).
	Electricity Law (1902) Electricity Ordinances (1994)	734.0 734.1 734.2 734.31	Govern the electricity sector in general.
Hydropower	Water Right Law (1916) Water Right Ordinance (2000) Ordinance on the compensation for foregone hydropower utilisation revenues (1995)	721.80 721.801 721.821	General regulation for hydropower, e.g. the water concession rights. Devolve the flood protection to the Cantons. Regulates compensation for non-use of hydropower for a site of national significance worthy of protection. (See Section 5.2.2.)
	Water Royalty Ordinances (1918) (1997)	721.831 721.832	Regulate royalties on the water use (see Section 5.2.2).
Dams	"Wasserbaupolizeigesetz" (1877) Barrage Ordinance (1998)	721.10 721.102	Regulate dam safety. (See also Section 5.2.3) A new law is currently being drafted to regulate dams as the current legislation is insufficient for small dams.
Environmental protection	Environmental Protection Law (1983) Environmental Impact Ordinance (1988)	814.01 814.011	Comments on the SHP plants and streams. SHP plants above 3 MW are governed by this ordinance (see Section 5.2.2).
Water bodies protection	Water Bodies Protection Law (1991) Water Bodies Protection Ordinance (1998)	814.20 814.201	Regulate environmental protection of streams, e.g. residual flow regulation, water quality, reservoir flushing, hydropeaking and disposal of floating materials (see Section 5.2.2).
Fishery	Fishery Law (1991) Fishery Ordinance (1993)	923.0 923.1	Regulate the protection of fish, e.g. their life environment and fish mobility upstream[1].
Nature and homeland	Nature and Homeland Protection Law (1966)	451	Regulate the protection of fauna and flora, river bank vegetation and valuable habitats (i.e. list the ecological

	Nature and Homeland Protection Ordinance (1991)	451.1	conditions for concession permitting).
Forestry	Forestry Law (1991)	921.0	Regulates forest clearing.
Spatial planning	Spatial Planning Law (1979) Spatial Planning Ordinance (2000)	700 700.1	Regulate construction outside of construction zones.

[1] *If possible, the fish mobility downstream should be safeguarded as well.*

Sources: in the table (see SR Number)

An overview of all Federal laws and ordinances related to hydropower in general can be found under the following link[93]. A specific search with keywords such as "energy" and "water" can also be made on the Federal administration website[94].

As it can been seen in Table 5-2, SHP is affected by multiple Federal legislations. The Federal government has the supervision of the use of hydropower on public and private streams[95], and the Cantons are in charge of the allocation of water concessions for water usage in most of the Cantons (in Valais and Graubünden it is the Communes, in Schwyz the Districts, in Uri the allmend and forest corporation and in Glarus the river bank owners). In the case of water concessions between Cantons, the Federal administration is in charge.

The Cantons have their own legislation relating to SHP, which differs between the Cantons. Besides legislating on water concessions, the Cantons determine as well the amount of the water royalties (see below). The Cantonal legislation follows the Federal requirement for establishing the enforcement regulation. Most Cantons have a water protection law, a water right law and a water construction law. Furthermore, the enforcement regulations for the use of water and flood protection are often combined. Some Cantons even have an overall water law including all these maters (e.g., Zug and Geneva). Zysset et al. present an overview of the main Cantonal laws (2007, Table 2) which is in the Appendix F. Section 5.2.3 describes the Cantonal legislation in the case of the Canton of Valais. Finally, certain Cantons offer low interest rates loans or loans without interest for SHP projects, they support pilot projects and can contribute to environmental compensation measures[96]. However, in about half of the Cantons there is no possibility for subsidies (Leutwiler, Bölli et al., 2011).

5.2.2 Policy instruments for SHP in Switzerland

There are different categories of policy instruments within the literature (Oikonomou and Jepma, 2008; Vöhringer, 2009; Oikonomou, Flamos et al., 2010). The main categories are legal or regulatory instruments, market-based instruments, financial and fiscal instruments, organisational measures, and research and information. Legal or regulatory instruments are often referred to as command-and-control and include standards, codes and permits. Market-based instruments include among others feed-in tariffs, tradable emission permits and green certificates. Financial and fiscal instruments refer to subsidies, grants and taxes. Organisation measures include negotiated and voluntary agreements such as legally non-binding press statements. Finally, research and information includes R&D, action plans, information campaigns and networking platforms.

[93] http://www.wasserkraftwallis.ch/?seo=de/wasserkraft/rechtliche-aspekte/rechtsquellen&id=33&language=fr (accessed on 01.11.2011)
[94] http://www.admin.ch/ch/f/rs/sachreg.html (accessed on 01.11.2011)
[95] All surface and underground streams are public, but in some cases the ownership can be private (e.g., sources and rivulets the land of a private owner according to Swiss Civil Code, Art. 667 and following).
[96] http://www.sta.be.ch/belex/f/7/751_11.html Art. 9 Paragraph 5 (accessed on 01.11.2011)

Figure 5-2 presents the main policy instruments for SHP in Switzerland by category of instruments. The instruments have been identified through the literature review and the interviews. Table 5-3 relates each instrument to its actors (in this cases the main stakeholder) and legislation. Each instrument is then developed in more detail following the chronology of Figure 5-2. In addition to the policy instruments, the water concession is described as well as it represents an important aspect of the institutional framework of SHP. The water concession is not a policy instrument, but an authorisation required to develop SHP projects.

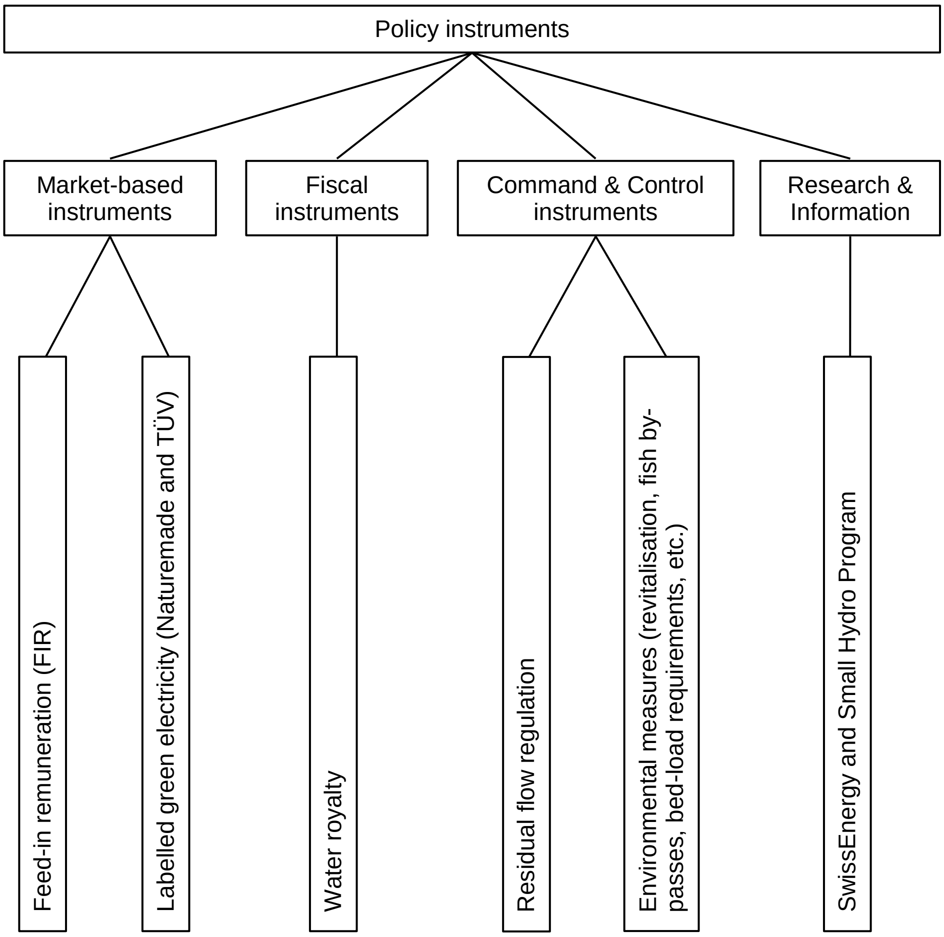


Figure 5-2: Main policy instruments for SHP in Switzerland

Table 5-3: Main policy instruments for SHP in Switzerland with involved actors and legislation

Policy instruments[1]	SHP specific or RETs in general	Actors (see Table 5-1)	Legislation (see Table 5-2)
Water concession	SHP specific	Cantonal or Communal authority[2]	Water Right Law
Feed-in remuneration (FIR)	RETs in general	SFOE, Swissgrid, Energiepool	Energy Law
Labelled green electricity (green tariffs)	RETs in general	Naturemade-VUE, TÜV	No legislation; private initiative.
Water royalty	SHP specific	Federal and Cantonal authority	Water Royalty Ordinances
Flow regulation: residual flow and hydropeaking	SHP specific	Federal and Cantonal and / or Communal authority	Water Bodies Protection Law
Environmental construction measures	SHP specific	Cantonal or Communal authority	Environmental Protection Law, Water Bodies Protection Law, Fishery Law, Nature and Homeland Protection Law
SwissEnergy and Small Hydro Program	RETs in general and SHP specific	Federal authority	Energy Law

[1] *Including the "water concession" as an authorisation and not as a policy instrument.*

[2] *For exception, see Section 5.2.1*

Water concession

SHP plants require a water use right concession (in short "water concession") to abstract water from the stream. The concession is delivered by the corresponding public authority (Canton, Commune or other – see Section 5.2.1) and lasts a maximum 80 years[97], which is aligned with the lifetime of the major part of the plant (i.e., civil works).

The water concession is given for a fixed river section, fixed flow and fixed head. The acquired right to use a given river section and flow cannot subsequently be annulled by later legislation nor can the flow be diminished in its substance. Should the river section, the flow or the head change beyond limits set by the corresponding authority, the concession has to be renewed.

The submission for a water concession must include technical plans, a technical report and the environmental impact assessment. SHP plants with an installed capacity above 3 MW are submitted to such an assessment[98]. Plants below 3 MW submit to an environmental impact note which is a less significant assessment. The assessments have to be done in cases of new construction, of significant changes of the plant, of significant changes to the existing concession and in case of renewal of the concession.

The conditions for the concession granting are based on the actual environmental legislation. Each concession comes along with obligations such as environmental construction measures (see below), maintenance measures, protection measures (e.g., for tapped sources), concession taxes, and the regulation of the reversion of the concession. For plants with an installed capacity above 300 kW, the SFOE has to be consulted concerning the technical use of the available hydraulic potential and safety. The FOEN and ARE are also consulted.

[97] Art. 58 of Water Right Law (see Table 5-2)
[98] http://www.admin.ch/ch/d/sr/814_011/index.html (accessed on 01.11.2011)

At the term of the concession, the “wet” parts of the plant (weir, pipes, turbine, etc.) are transferred for free to the authority who granted the concession. This is approximately 75% of the plant value for hydropower (Plaz and Hanser, 2008: 67). The “dry” part (electrical installations), which corresponds to about 25% of the plant value, can be bought for its residual value by the concession granting authority. The total value coming from the “wet” and “dry” part is split between the Canton and the Communes affected by the concession (splitting varies among the Cantons). Most concession reversions will occur between 2035-2055 (Plaz and Hanser, 2008). In case the authority does not wish to take over the plant, it can either be sold back to the former operator, auctioned or a specific public-private-partnership set up.

Feed-in remuneration

The Swiss feed-in remuneration (FIR) was introduced on the 01.01.2009. The FIR applies to RETs which are not yet cost-competitive in the liberalised electricity market, including SHP. From the legal point of view it is not a “tariff” nor a subsidy, but a feed-in remuneration schemes (Leutwiler, Bölli et al., 2011) [99].

Before the FIR was introduced and since 1992, MHP, and only MHP, operated by independent producers benefited from a guaranteed feed-in tariff called “Mehrkostenfinanzierung (MKF)” of 16 cts/kWh (1992-1999) or 15 cts/kWh (after 1999). However, only the electricity surplus could be sold after deduction of the consumption of the owner (e.g., manufacturing company). The local electricity distribution companies purchased the electricity from MHP plants paying the MKF. In opposition to today’s FIR scheme, the MKF was not considered to cover the “greenness” of the MHP electricity, i.e. the value as a RET. The electricity distribution companies could thus sell the ”greenness” of MHP electricity through labelled green electricity (see below). MKF is guaranteed until 2035 if the plant became operational before 2006. From 01.01.2006 on, the current FIR scheme is in force for new and rehabilitated[100] plants and MKF is paid from the FIR fund instead of being paid by the local electricity distribution companies[101]. In 2010, 480 plants receiving the MKF produced 348.1 GWh (Stiftung Kostendeckende Einspeisevergütung (KEV), 2011). MKF has not been adapted to inflation.

Today’s FIR depends on the installed capacity, yearly production, head and a bonus linked to the hydraulic civil work. The remunerations are based on reference plants. The maximum amount for SHP is 35 cts/kWh. There is no digression of the remunerations in time, but the FIR can be adapted at any time by the Federal Department of the Environment, Transport, Energy and Communications (DETEC). The remuneration is guaranteed for 25 years from the day the plant starts to operate. The FIR considers an internal return rate (IRR) of 5% and an operating costs flat-rate of 2%[102]. There are no ecological constraints to it; however all the environmental regulations must be fulfilled in order to get the water concession. The FIR cannot be combined with the labelled green electricity market.[103]

Rehabilitated plants can also apply for the FIR if they fulfil one of the two following requirements. Either the production is increased by 20% compared to the average of the last five years of operation before 01.01.2011; or the investment is at least 50% of the investment for a new plant, while considering the investments of the last five years before the rehabilitation. In the case of the investment requirement, the production is not allowed to decrease, but new residual flow and hydropeaking regulation are considered. If the plant already receives the FIR, the age of the plant to rehabilitate has to correspond at least to two thirds of the payment duration of the FIR.

[99] The FIR is a cost-effective net metering and defined in the Energy Law, Art. 7a.

[100] The conditions for rehabilitated plants for applying for FIR are given in the Federal Energy Ordinance (see Section 5.2.1).

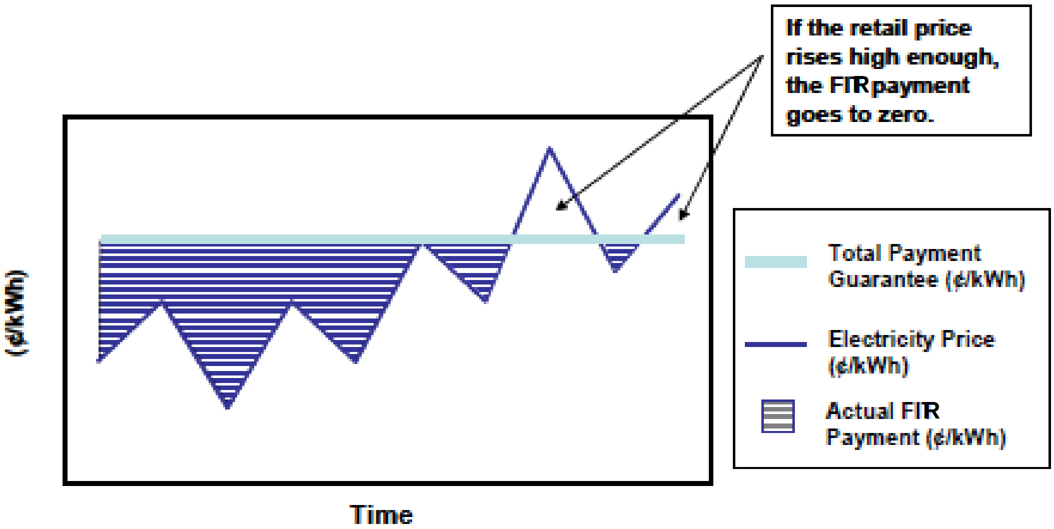
[101] For questions between MKF and FIR, information can be downloaded from the SFOE website: http://www.bfe.admin.ch/themen/00612/02073/index.html?lang=de&dossier_id=02168 (accessed on 31.10.2011)

[102] This rate is much too low for small MHP plants and too high for big SHP plants (personal communication with Interviewee CH-6).

[103] More information can be found in the SFOE Guidelines (BFE, 2008a, 2008b) and a calculation tool can be downloaded on the SFOE website (http://www.bfe.admin.ch/kleinwasserkraft/index.html?lang=de&dossier_id=03893 (accessed on 01.11.2011)) in order to evaluate the FIR for a given plant. Appendix L.3 shows the calculation tables in English.

To finance the FIR scheme, the Energy Law stipulates that, with effect from 01.01.2009, a maximum surcharge of 0.6 cts/kWh from Swiss electricity final consumption can be levied, corresponding to a potential fund of 320 million CHF per year. This fund increases with increased electricity consumption. Initially, the surcharge was fixed at 0.45 cts/kWh, and in 2010, the maximum surcharge was increased by the Federal parliament to 0.9 cts/kWh from 01.01.2013 on[104]. Final customers who spend more than 10% of the gross value added for electricity are exempt from paying the FIR contribution[105].

SHP can benefit from a maximum of 50% of the FIR available fund[106]. The fund pays the difference between the set FIR and the market price at the moment of production, i.e. a premium-fix FIR (see Figure 5-3). The market price is taken from the Swissix trading price. Increasing electricity market prices reduce therefore the costs covered by the fund. The unspent money within the fund is kept to cover future fluctuation in the market price and to ensure investment risks of future geothermal projects. Some money from the fund goes as well towards the tendering of projects related to energy efficiency. Finally, starting in 2012, an amount corresponding to 0.1 cts/kWh goes towards the revitalisation project linked to hydropeaking projects (see below).



Source: Figure adapted from (Cory, Couture et al., 2009: 6)

Figure 5-3: The Swiss premium-fix FIR

All administrative procedures are done through the KEV/RPC foundation[107] which has been created by the national TSO, Swissgrid. Firstly, the application[108] for the FIR for a SHP project has to be submitted to Swissgrid which notifies the operator if its project is accepted or not[109]. Swissgrid notifies if funding is still available or if the demand goes on the waiting list till further funding is available. If the SHP project is allocated the FIR, the water concession and construction permit to build the plant have to be obtained within four years after the allocation of

[104] As funding remains limited for a couple of years, a motion passed in Federal parliament in September 2011 suggests that the ready to be built projects should be promoted with yearly contingents http://www.parlament.ch/d/suche/seiten/geschaefte.aspx?gesch_id=20113331 (accessed on 30.09.2011)
[105] http://www.bfe.admin.ch/themen/00612/02073/index.html?lang=de&dossier_id=04355 (accessed on 31.10.2011)
[106] For example, in the third quarter 2011, SHP received 37% of the FIR payments (http://www.stiftung-kev.ch/fileadmin/media/kev/kev_download/de/111219_KEV_Reporting_11Q3_kurzV2.pdf (accessed on 03.0.2011).
[107] http://www.stiftung-kev.ch/willkommen.html (accessed on 31.1.2011)
[108] The final site of the plant can vary within a one km of the site in the application. The installed capacity can vary arbitrarily. The written approbations of a land owner affected by the plant have to be submitted with the application, as well as a statement of the authority granting the water concession recording that from a technical and legal perspective the project is feasible.
[109] Guidelines and FAQ for applications can be found on the Swissgrid website: https://www.swissgrid.ch/swissgrid/de/home/experts/re/crf/hydropower.html and https://www.swissgrid.ch/swissgrid/de/home/current/faq/faq_crf.html (accessed on 31.10.2011)

the FIR[110]. The plant has to be operating within six years after the allocation of the FIR. The commissioning of the FIR occurs with Swissgrid.

The authorities are submerged with project demands. As of 18.01.2012, around 245 SHP projects are financed through the FIR with 484 GWh/year and 106 MW installed (see Table 4-11). In addition, there are nearly 400 approved projects (1'380 GWh and 348 MW) and even more projects on the waiting list[111]. The projects on the waiting list are projects which applied once all the FIR funding was already allocated. Such projects therefore wait for future FIR fund increase. Due to this large number of new projects, the FOEN, SFOE and ARE published recommendations for Cantonal water use and protection strategies related to SHP (BAFU, BFE et al., 2011) (see also Sections 4.2.2 and 6.1).

If a producer can obtain more remuneration through labelled green electricity or another market, he can switch on a yearly base from the FIR scheme to the market. In case of switching back, he will have to apply again for the FIR and thus may end up on the waiting list. The reference year for the calculation of the FIR remains the first year of operation.

Labelled green electricity (green tariffs)

Two labels in Switzerland allow SHP plants to make additional income for the "greenness" of their produced electricity - Naturemade and TÜV. Naturemade[112] is a Swiss label for green electricity and recognised by ProNatura, WWF and Greenpeace, and is recognised as well at the European level. A labelled SHP plant can sell the ecological value of its electricity at an increased price to consumers requesting labelled green electricity from RETs. Naturemade has two products. Naturemade Basic for SHP only requires a declaration of the source and origin of electricity. Naturemade Star has been designed for environmentally preferable electricity. Naturemade Star labelled SHP plants have to fulfil additional environmental standards, the so called greenhydro standards (Bratrich and Truffer, 2001), in order to have a lower environmental impact than traditional hydropower plants. The environmental standards concern residual flow, hydropeaking, the continuity of the watercourse, etc. SHP plants within infrastructures have some simplifications within the labelling scheme. Hydropower plants with more than 100 kW installed capacity must establish a fund to improve the ecological state of the SHP plant site or its vicinity. The funds are financed from a levy on labelled electricity. The price premium for the ecological value with Naturemade Star changes between 3 cts/kWh 8 cts/kWh[113].

In November 2011, 79 plants producing 380 GWh, which represents about 5.5% of all SHP plants, respectively about 9.6% of SHP production, were labelled Naturemade Star. 8 plants producing 65 GWh, which represents 0.6% of all SHP plants, respectively 1.6% of SHP production, were labelled Natuemade Basic [114]:

Large hydropower also benefits from the label and, in November 2011, produced 728 GWh under the "Naturemade Star" label and 8'898 GWh under the "Naturemade Basic" label. There are less labelled plants than for SHP, but significantly more production. The administrative procedures costs are, in relative terms, lower for large hydropower.

The labelling costs depend on the yearly production and are composed of fix and variable costs[115]. The fixed costs are the same for Naturemade Basic and Naturemade Star. The variable costs depend on the production. Finally, yearly audit fees have to be added to the labelling costs.

[110] Some deadline extensions can be obtained.
[111] https://www.guarantee-of-origin.ch/reports%5CDownloads%5Cwarteliste_DE.pdf (accessed on 18.01.2012)
[112] http://www.naturemade.org (accessed on 01.11.2011)
[113] http://www.topten.ch/deutsch/oekoenergie/oekostrom/wasser.html (accessed on 03.02.2011)
[114] http://www.naturemade.org/Franz/Label/label_f_aktuell.htm 15.11.2011 (accessed on 03.02.2012)

In addition to the labelling costs are the costs required for environmental integration measures to obtain the label, especially in the case of Naturemade Star. These costs are much more important than the labelling costs. For projects using older infrastructures or existing projects, the costs are higher than for new plants. The costs can be very high in relative terms for MHP projects.

The TÜV label can also be used to label hydropower production, but in comparison to Naturemade Star, it does not contribute to an added ecological value for SHP plants (Siegfried, Bolliger et al., 2008: 24).

Swiss cities, committed to RETs for electricity production, are major buyers of such labelled SHP production. Furthermore, more and more electricity suppliers offer the possibility of purchasing an electricity mix from RETs thanks to labelled green electricity for individual customers[116]. If more end users demand green electricity from RETs, this will contribute to the facilitation of these technologies.

Water royalty

The water royalty must be paid by the holder of a water concession for abstracting and using water for hydropower. It is based on the installed capacity and not on the actual amount of water used. It is regulated by the Water Royalty Ordinance (see Table 5-2). The Federal government has been setting the maximum water royalty since 1918. The Cantons then define the water royalty for their Canton which can be lower than the maximum. The split up of the revenue between the Canton and the Communes varies among the Swiss Cantons. In most Cantons, the water royalty goes totally to the Canton. In the Canton of Graubünden, the rental is split evenly between Canton and Communes. In the Canton of Valais, the rental of the main river Rhone goes to the Canton, whereas 40% of the rentals of the other streams go to the Communes (Leimbacher, 2008).

Figure 5-4 shows the progression of the maximum water royalty compared to the installed capacity[117] (see also Section 4.1.1). MHP was exempt from the rental in 1997 which reduced average production costs by 1 ct/kWh (Leutwiler, 2006). The rental increases linearly between 1 and 2 MW to reach to maximum amount which is currently 100 CHF/kW. It has been increased from initially 8.2 CHF/kW in 1918 to 80 CHF/kW in 1997 (see Figure 5-5) and to 100 CHF/kW on the 01.01.2011. It will increase to 110 CHF/kW on the 01.01.2015.

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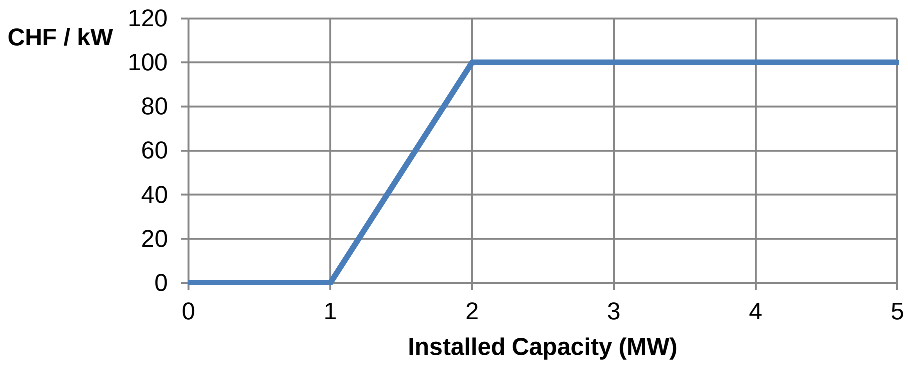
[115] http://www.naturemade.org/Dokumente/zertifizierung/Geb%C3%BChrenordnung%20V1.2.pdf (accessed on 02.11.2011) and personal communication with VUE-Naturemade 02.11.2011.

The yearly fee consist of the yearly licence fee of 200 CHF and yearly membership fee of 1'000 CHF to be part of VUE which is in charge of the Naturemade labels (No membership fee in case of production below 5 GWh).

For example with 20 GWh a year, the variable licence costs for Naturemade Star are 1'200 CHF, whereas with Naturemade Basic they are 850 CHF. Furthermore, the labelling procedures have to be renewed every 5 years which costs 500 CHF. The yearly audit fees are about 800 to 1'000 CHF. As example, a SHP plant producing about 20 GWh a year has labelling costs of about 3'300 to 3'500 CHF a year (in the case of 4 GWh, only 1'450 to 1'650 CHF).

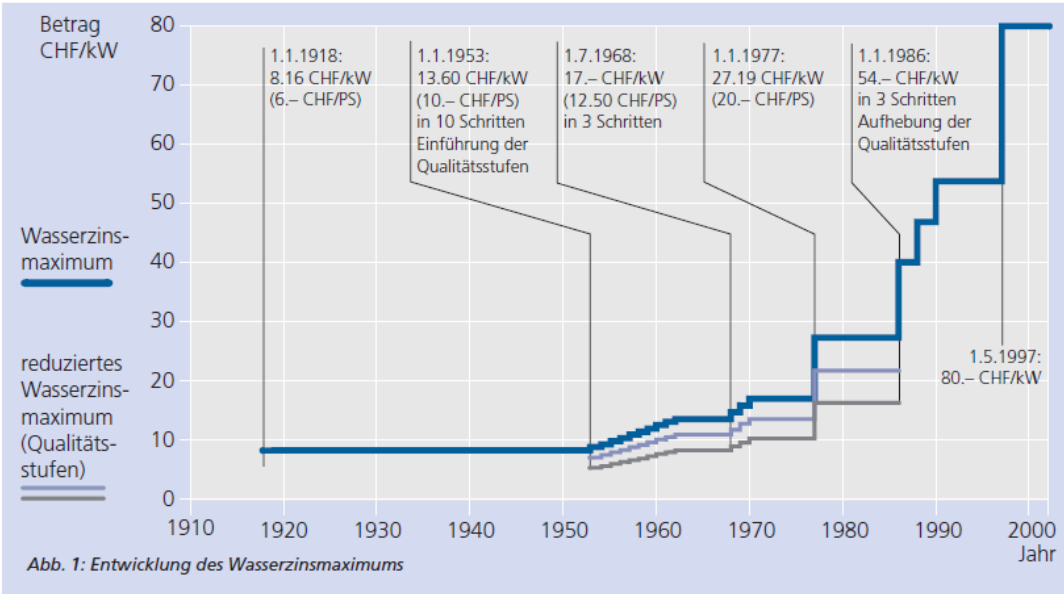
[116] For example, the public utility in Lausanne with Nativa (http://www.lausanne.ch/view.asp?docId=35960&domId=65191&language=E (accessed on 03.02.2012))

[117] See Section 4.1.1 for the definition of the installed capacity.



Source: http://www.admin.ch/ch/f/rs/721_80/a49.html Art. 49, paragraph 4

Figure 5-4: Water royalty in function of the installed capacity



Source: (Sigg and Röthlisberger, 2002: 12)

Figure 5-5: Evolution of the maximum of the water royalty

Flow regulation – residual flow and hydropeaking

Article 31 of the Federal Water Protection Law regulates the residual flows. The residual flow is the minimum flow which needs to remain in a stream downstream of the water intake. It is based on the Q_{347} which is the flow that over a period of 10 years is in average reached or exceeded on 347 days a year. The residual flow in function of the Q_{347} can be found in the Law[118]. The lowest value is 50 l/s. For SHP projects with an installed capacity above 300 kW, the FOEN has to be consulted for the setting of the residual flow value.

Article 32 of the Federal Water Protection Law states the exceptions where the legal residual flow value can be underrun because the stream is of less environmental value[119]. There are some examples[120]. The minimum can be underrun, for example, in the case in small rivulets above 1500 m above sea level. Furthermore, within a

[118] http://www.admin.ch/ch/d/sr/814_20/a31.html (accessed on 01.11.2011)
[119] http://www.admin.ch/ch/d/sr/814_20/a32.html (accessed on 01.11.2011)
[120] Interview CH-11, VS-8

“protection and use plan” (Art. 32 c.), the residual flow can be underrun if adequate compensation measures are taken at another site in the same topographical-hydrological unit. Such measures include the “no use” or “use with higher residual flow” on another site where the environmental value of the stream is higher, the rehabilitation of river sections, or the enabling of fish migration on former obstacles in the river (Bolliger, Zysset et al., 2009). In 2011, there were 16 protection and use plans, including 5 concerning SHP plants[121]. This regulation aims for a given area at an appropriate balance between protection and use. The number of such protection and use plans could be increased in order to further develop SHP within a regional planning of its development. This is more likely to happen in Cantons where the water concessions are delivered by the Canton. However, the Federal government must approve such “protection and use plan” which limits the leeway of the Cantons.

Another instrument which compensates the “no use” of a site with hydropower potential, but within a landscape of national significance, is the compensation for hydropower losses (see Table 5-2). In 2010, three out of the nine concerned compensation projects were SHP plants[122]. The compensation is financed through the water royalty (see above).

Article 33 states the procedures for the evaluation when the legal residual flow value has to be increased compared to the initial regulation in Article 31. It is mainly for environmental, ecological and agricultural reasons. This Article is currently seldom applied by the Cantons (BFE, 2007c: 108).

The issue of hydropeaking needs to be raised as, later in this research, storage and pumped-storage SHP plants are evaluated. Hydropeaking describes the fluctuation in the water flows due to hydropower operations. In times of high electricity demand, much more water is released in the river than in times of low demand. The amplitude between high and low water levels defines the hydropeaking. Hydropeaking happens more frequently than flooding and significantly affects the ecological life balance. In winter, when the water level is low, hydropeaking has major environmental impacts including changes to the water flow, water temperature, the wetted stream width, flow velocity and sediment transport. Smaller rivers have less sensibility to hydropeaking than larger rivers as they are more exposed to naturally significant flow fluctuations (BAFU, 2011). Following the environmental law changes (see below), all hydropower plants concerned by hydropeaking will have to be identified. Thus the development of storage and pumped-storage SHP plants will need to consider the new regulation on hydropeaking.

Plants need to take construction or operational measures against hydropeaking when indigenous flora and fauna, as well as their habitats, are significantly affected. The law defines this by two factors (Water Bodies Protection Ordinance , Article 41e)[123]:

- The hydropeaking has a ratio above 1.5 to 1 (high flow to low flow),
- The site-specific quantity, composition and diversity of flora and fauna are adversely affected.

When both are affirmative, measures need to be taken. However, these factors need to be further elaborated as the scientific literature remains weak for the time being (BAFU, 2011). Research on the topic is currently conducted at the EPFL and EAWAG [124].

Measures must be adapted to the catchment area and depend on the ecological value, the proportionality of the effort, the interests of flood protection and energy policy objectives to facilitate RETs. Some examples of measures are derivations in a reservoir, higher residual flows and lower changes of flow in operational mode. The measures are partly financed through a subsidy of 0.1 cts/kWh on the electricity from the final consumers. This

[121] (Bolliger, Zysset et al., 2009) and personal communication with FOEN, May 2011.
[122] Personal communication with SFOE, December 2010
[123] http://www.admin.ch/ch/d/sr/814_201/a41e.html (accessed on 27.09.2011)
[124] E.g. http://lch.epfl.ch/page-7702-en.html (accessed on 27.09.2011)

amount is part of the amount taken for the FIR scheme (see above). All legal regulations can be found in the appendix of the Federal strategic planning on hydropeaking (BAFU, 2011).

The residual flow and hydropeaking regulations are relevant for the later research which looks at the possibility of dynamic residual flow. Furthermore, the regional "protection and use plan", as well as the "no use" compensation schemes within the residual flow regulation matter for the regional development of SHP as developed in Section 6.1.

Environmental construction measures

The Federal Fishery Law states that appropriate arrangements should be made to allow free fish migration when a stream is used. However, no distinction between upstream and downstream migration is currently made and downstream migration is not explicitly mentioned. Often, only facilities for the upstream migration are provided (e.g., fish by-pass). Efforts are currently being made for the implementation of equipment with facilities for downstream migration such as fish-friendly turbines.

The Federal Water Protection Law and its Ordinance regulate the bed-load balance. The balance is maintained so that no significant impact results for the endemic flora and fauna, the habitats, the groundwater balance and the flood protection. The bed-load should pass through the installation on the stream to the maximum level possible. The SHP owners are obliged to provide all necessary information on their bed-load handling, measures, and operational and structural adaptations.

SHP projects located in Federal or Cantonal registered environmental sites, such as those for groundwater or fish protection (floodplains, moorland areas, spawning areas, etc.), are highly likely to be rejected. The competent authority will not deliver the water concession. Maps of the inventoried sites can be found online on the FOEN website[125].

Furthermore, in December 2009 the Federal parliament passed changes in the Water Bodies Protection Law, Water Right Law, and the Energy Law. The changes came as a response to the popular initiative “living waters”[126]. They became effective on 01.01.2011 and concern the revitalisation of streams and the reduction of negative impacts by reducing the effects of hydropeaking (see above), by reactivating sediment transport and by restoring the water continuity for fish migration (Göggel, 2012). The revitalisation comes as response to the fact that 15’000 km, or 25%, of all streams are assessed “strongly affected” by human-made measures. The revitalisation is a renewal process to return to the original status so that the water can fulfil its natural functions. The goals of the revitalisation are among others manifold water structures, secured interconnectedness and clean water. SHP projects for new plants or rehabilitation of existing ones can contribute to these goals in already complete artificially modified river sections. Therefore, synergies between SHP development and streams revitalisation can be developed. On the other hand, some existing SHP plants will have to take measures of revitalisation irrespectively from rehabilitation because the Federal parliament has decided that 4’000 km of streams have to be revitalised and the use of hydropower made more ecological by 2030. Some SHP plants will have to improve the fish migration, thus build fish-bypasses. Such measures can be financed by the revitalisation fund which is fed by 0.1 cts/kWh on the electricity from the final consumers (same subsidy fund than for hydropeaking measures, see above). Construction measures to improve the fish migration are fully financed for SHP plants with an on-going water concession or in the case of the renewal of the water concession without expansion of the plant.

[125] http://www.bafu.admin.ch/hydrologie/01835/02114/02116/index.html?lang=en (accessed on 01.11.2011)
[126] http://www.parlament.ch/d/suche/seiten/geschaefte.aspx?gesch_id=20070060 (accessed on 01.11.2011)

Finally, the current Water Protection Ordinance is under on-going revision[127]. Certain SHP stakeholders fear that with the FIR scheme additional pressure is being used to exploit river sections which are not currently used for hydropower. These stakeholders want to protect such river sections by introducing a new article in the Ordinance. A decision can be expected in 2012.

The environmental construction measures belong to the key policy instruments for SHP. However, as the focus of research is not on the environmental aspects and as these policy instruments have just be reviewed, they were not part of the later analysis.

SwissEnergy and Small Hydro program

The Federal government continues to support SHP through its “SwissEnergy” program (see Section 2.2.3)[128] whose long term goal is the 2’000 Watt society (see Section 2.2.4). Part of the “SwissEnergy” program is the Small Hydro program[129].

The focuses related to RETs of the SwissEnergy program lie in improving the institutional framework, the information and communication and in promoting quality assurance. These focuses are also part of the Small Hydro program.

The goals of the Small Hydro program are: 1) to contribute to increase the use of the SHP potential (new plants and rehabilitation), 2) to strengthen the position of SHP in general, 3) to coordinate and involve stakeholders, and 4) to seek synergies with other technologies and domains (Leutwiler, Bölli et al., 2011).

The main activities are:

- the provision of information and advice: five information centres have been created that offer services in German, French and Italian;
- the support of projects (supporting project promoters in their efforts from original concept through to operation and by including the interests of other stakeholders at the earliest possible stage):
    - supporting broad analysis of concrete projects with site visits (financial support of 2’000 CHF if the total costs are at least 3’500 CHF which is generally the case);
    - supporting pilot and demonstration plants (no funding has been given since 2003) (Leutwiler, Bölli et al., 2011);
    - providing information sheets[130];
- communication: media activities, web site[131] and electronic newsletters (three issues a year), attendance at selected events;
- the networking with the various stakeholders: providing a platform.

Research and development activities were integrated into the Hydropower research program in 2008.

Previously to the Small Hydro program, two other programs took place, PACER and DIANE. PACER (Program d'Action Energies Renouvelables) was initiated by the former Federal Office of Economic Affairs in 1990 and concluded in 1996. It aimed at promoting SHP by providing detailed information and decision-making bases for owners of water rights, Communes, Cantonal authorities, engineers and entrepreneurs. It drew attention to the

[127] http://www.admin.ch/ch/d/gg/pc/documents/2029/GSchV_d.pdf (accessed on 01.11.2011)
[128] http://www.energieschweiz.ch/de-ch/home.aspx (accessed on 01.11.2011)
[129] http://www.bfe.admin.ch/kleinwasserkraft/03870/index.html?lang=en (accessed on 01.11.2011)
[130] http://www.bfe.admin.ch/kleinwasserkraft/03870/03873/index.html?lang=en&dossier_id=03890 (accessed on 01.11.2011)
[131] http://www.bfe.admin.ch/kleinwasserkraft/index.html?lang=en (accessed on 01.11.2011)

well developed technology of hydropower and extended it to areas in which it was little used at that time. Several publications resulted from this program[132].

DIANE (Durchbruch Innovativer Neuer Energietechniken) aimed at achieving breakthroughs in innovative energy technologies and was developed within the program “Energy 2000”. It lasted from 1990 till 1996. DIANE facilitated SHP by studying potentials and analysing obstacles to SHP development. Thanks to systematic media activity, the degree of public acceptance of SHP plants was greatly increased. DIANE also offered information and consulting services, as well as created a variety of tools. Several publications also resulted from this program[133]. Following DIANE, the Small Hydro program was initiated to continue the facilitation of SHP.

5.2.3 The institutional framework in the Canton of Valais

This Section describes the legislation in the Canton of Valais related to SHP, as well as specific Cantonal institutional aspects. It also briefly presents the key role of the Commune.

The Canton of Valais established a law concerning the water right concession for hydropower in 1898 before the Federal Water Right Law of 1916 (see Table 5-2). However, once the Federal law was into force, the Cantonal law only remained significant on the topic of concession reversion. This topic is currently being reviewed in view of the concession reversion of large hydropower plants in order to increase the ownership of the Canton and the Communes within new concessions and in order to distributed the financial benefits more equally within the Canton than is currently the case (Cina, Balet et al., 2011). It will also affect SHP plants which have concessions coming to an end in the coming decades. Among the discussed options is the idea of differentiating the water concession regulation for SHP and large hydropower in order to give more decisional power at the local level in the case of SHP plants.

In the Canton of Valais, it is the communes which deliver the water concession. These Communes are very different across the Canton. They are 141 Communes, with populations of between 20 and 29’000 habitants, surfaces between 0.7 and 282 km^2, and different altitudes[134]. The water supply for each Commune has its own characteristics. Some Communes receive their water solely from altitude sources; others have to pump up groundwater. Current water projects aim at increasing the interconnection between the Communes in order to increase use efficiency of the available water resources. Within these interconnection projects, SHP could be integrated to develop multipurpose infrastructures. Overall, more convergence between Communes and sectors would be beneficial to optimise water management.

In analogy to the Federal legislation, Table 5-4 summarises the key laws and ordinance related to SHP at the Cantonal level.

[132] http://www.bfe.admin.ch/kleinwasserkraft/03870/03874/index.html?lang=en&dossier_id=03892 (accessed on 01.11.201)
[133] http://www.bfe.admin.ch/kleinwasserkraft/03870/03874/index.html?lang=en&dossier_id=03891 (accessed on 01.11.2011)
[134] http://www.vs.ch/Navig/navig.asp?MenuID=14764&language=fr : Le Valais en Chiffre_2010.pdf (accessed on 16.08.2011)

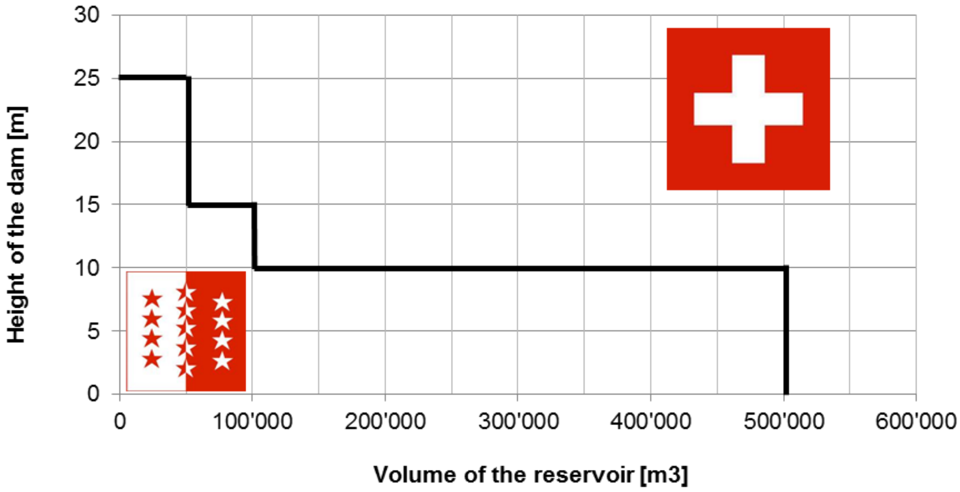
Table 5-4: Cantonal laws and ordinance relating to SHP in Valais

Domain	Name	Number	Description / Specificity for SHP
Energy	Energy Law (2004)	730.1	Communes can force house owners to connect to a grid or installation providing mainly renewable energy (Art. 10). Creation of a fund to finance facilitation measures, including for RETs (Art. 19).
	Ordinance on the facilitation measures in the energy domain (2004)	730.101	Financial support from the Canton for energy project (Art. 2) -> could support innovative SHP projects
Hydropower	Law on the use of water power (1990)	721.8	Regulates the use of water for hydropower production: - Liability insurance (Art. 46) - Renewal of water concession (Art. 61) - Exemption of the administrative fees for plants below 3 MW (Art. 64) - Fee for pump plants (Art. 68, see also below)
Stream	Law on the development of streams (2007)	721.1	Regulate the development of streams.
	Ordinance on the development of streams (2007)	721.100	
Construction	Construction Law (1996)	705.1	Regulate construction.
	Construction Ordinance (1996)	705.100	
Spatial planning	Law on the application of the Federal Spatial Planning Law (1987)	701.1	Details the Cantonal application of the Federal law.

Sources: in the table (see Number)

In the case of storage plants particular attention is given to the security of the dams. The Federal state is in charge of the surveillance of the dams, but delegates the surveillance for small dams to the Cantons (see Figure 5-6). Most of the storage and pumped-storage SHP plants fall under this category. The Federal state remains in charge for dams which are part of a unit of several storage facilities whereby one of them is already under the responsibility of the Federal state[135]. In addition, if a dam was under the surveillance of the Federal state under the previous regulation, it remains under the Federal state surveillance[136].

[135] Barrage Ordinance (1998), Art .23, al. 2
[136] Barrage Ordinance (1998), Art .29, al. 2



Remark: Dams smaller than 5 m and with less than 500'000 m^3 are under surveillance if they represent a particular danger to persons and goods.

Source: http://www.admin.ch/ch/f/rs/721_102/index.html (accessed on 16.08.2011)

Figure 5-6: Authorities in charge of the surveillance of dams
Federal state or Cantons (in this case Valais) according to the Barrage Ordinance (Art. 21 and 22)

In the case of pumped-storage plants, a pump fee has to be paid in certain cases (see Table 5-4, Law on the use of water power). This fee is of maximum 0.15 cts/kWh and in case of SHP minimum 0.5 CHF/kW. The fee is reviewed every 5 years and the generated income divided between the Canton and the Communes concerned with the same distribution key as for the water royalties.

With the introduction of the FIR, many new projects are developed. The Canton wishes to have a Cantonal master plan, but as the Communes have the water sovereignty, the implementation of such a plan remains very difficult. A riverine zone approach (see Section 6.1), in opposition to a single project approach, can only be chosen in Communes with a big surface or in Communes which are going to merge. The Communes remain therefore key actors for the SHP development in the Canton of Valais.

From an institutional facilitation perspective, there are no specific instruments concerning SHP development at the Communal level. The Canton, however, wants to further simplify, streamline and coordinate the administrative procedures (Cina, Balet et al., 2011).

Finally, it has to be noted that within the electricity sector in the Canton of Valais, the network of the involved actors is very complex. There are 34 hydropower companies in the Canton producing between 10 and 2'300 GWh[137]. Some companies have cross-shareholdings. SHP plants are developed by these companies and sometimes by the Communes themselves. A key role is placed by the Forces Motrices Valaisannes (FMV)[138], which the Canton owns with 51% and is regulated by an own Cantonal law[139]. The main goals of the FMV are to contribute to the development and utilisation of the hydropower and to secure the electricity distribution of the Canton in order to safeguard the development of the Canton (Staatrat des Kantons Wallis, 2008). These goals have a public service aspect, but are not based on a monopolistic situation.

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[137] Plan cantonal d'assainissement des cours d'eau, Annexe 2 – Sociétés hydroélectriques dans le Canton du Valais, 2007. Figures confirmed by Service de l'énergie et des forces hydrauliques, Canton of Valais, 24.10.2011.
[138] http://www.fmv.ch/fr/index.htm (accessed on 16.08.2011)
[139] http://www.vs.ch/public/public_lois/fr/LoisHtml/frame.asp?link=731.1.htm (accessed on 16.08.2011)

5.2.4 Policy instruments in neighbouring countries and in the literature to facilitate SHP

It is beyond the scope of this research to identify and compare all existing policy instruments which facilitate SHP. This Section offers some general perspectives mainly based on the institutional frameworks in Europe for RETs and in particular SHP. It is a brief literature review and contributes to shape the ideas developed in Chapter 6.

The major part of the literature concerns the economic facilitation of RETs. Policy instruments which are used to support RET development include taxes (e.g., quota obligation, taxes incentives), economic incentives (e.g., feed-in tariffs, governmental grants), and property rights creation along with the market creation for trading of these rights (RET certificates, certified emissions reduction). Instruments can be technology specific in which case they aim at eliminating or lessening the obstacles and market failures related to the facilitated technology. RETs have different stages of maturity and therefore the mix of policy instruments to facilitate them must be adapted accordingly. At the core of the various facilitation designs lays the assumption that it should target the maximisation of the social welfare function (Oikonomou, Flamos et al., 2010).

Table 5-5 shows an overview of the different policy instruments.

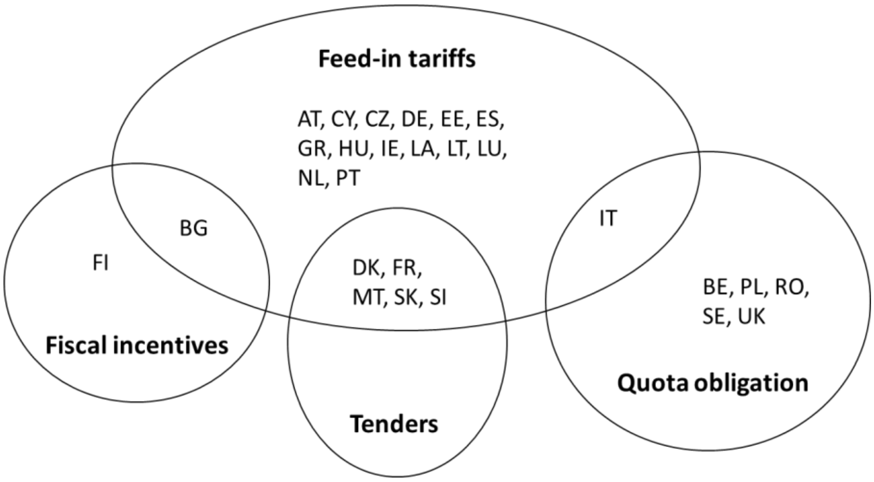
Table 5-5: Policy instruments (mainly economic) to facilitate RETs

		Direct		**Indirect**
		Price-driven	Quantity-driven	
Regulatory	Investment focus	Investment incentives Tax credits Low interest/soft loans	Tendering system for investment grants	Environmental taxes Simplification of authorisation procedures
	Generation based	Feed-in tariffs Fixed premium systems	Tendering system for long term contracts Tradable green certificates	
Voluntary	Investment focus	Shareholder programs		Voluntary agreements
	Generation based	Green tariffs		

Source: (Haas, Panzer et al., 2011: 1012)

Regulatory instruments are put in place by the government. Investment focus instruments support RETs usually per unit of generation capacity, whereas generation based instruments offer payment per unit of generated electricity. Price-driven instruments set the price first at a predefined level and the market then decides the quantity produced. Quantity-driven instruments set the quantity to be produced first and the price develops according to the market. Beside direct instruments which facilitate RETs immediately, indirect instruments such as eco-taxes on electricity produced by non-RETs contribute to supporting renewable energy development with a more long-term perspective. Finally, voluntary instruments are set up by private actors.

Within Europe, there is a large variety of applied instruments which facilitate RETs economically. Figure 5-7 summarises the dominating ones in the EU.



Source: (SHERPA, 2008d; Haas, Panzer et al., 2011, Table 3)

Figure 5-7: Dominating policy instruments which facilitate RETs economically in the EU

Feed-in tariff (FIT) schemes guarantee a fixed financial remuneration per unit of electricity produced from RETs (see also Section 5.2.2 for the corresponding Swiss feed-in remuneration) The support can be for both the physical electricity and the ecological value together (fixed FIT), or solely a premium for the ecological value (premium FIT). In the latter case, the producer sells the physical electricity on the regular market. FIT are determined by public authorities, are technology specific and are guaranteed for a specified period of time (e.g., 25 years). A fixed or regularly determined digression of tariffs over time can be used in order to reflect for economies of scale and learning. The exact quantity of facilitated electricity is not known ex ante.

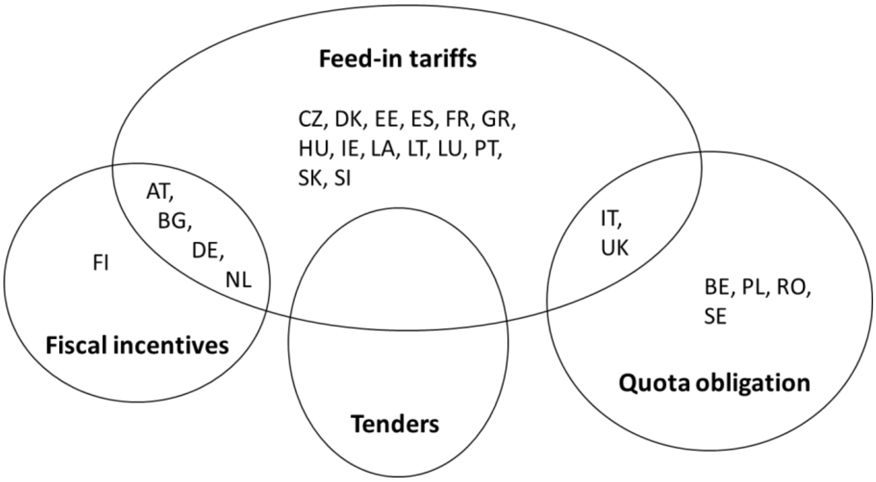
Quota obligations impose a fixed quota of electricity from RETs within the overall electricity mix. The obligation can be imposed on producers, retailers or customers. A quota obligation is often combined with tradable green certificate (TGC) schemes, for example in the UK. It can be seen as a property right which can be traded. The “greenness” represents the renewable electricity production. Liable entities have the possibility of generating the quota of electricity from RETs themselves or purchasing certificates for specific amounts from other operators. The financial value of the certificates is determined by the level of the quota obligation, the size and allocation of the penalty in case of not fulfilling the obligation, and the duration for which producers are eligible. Minimum tariffs for the certificates can be introduced in order to increase investment security. So as to support specific technologies, separate quotas per technology and technology-specific certification periods can be introduced. Producers sell their electricity on the electricity market and certificates on the green certificates market. The exact quantity of facilitated electricity is known ex ante, but not the price for it. Quota and TGCs are seen to be more adapted for well developed RETs that are close to competitiveness with conventional electricity production technologies, whereas FIT schemes are needed to induce innovation and cost-reduction on more costly and less developed RETs (Johnstone, Haščič et al., 2010).

In case of tendering, the public authority defines the quantity of electricity from RETs which is tendered. Competition focuses on the price per kWh proposed during the tendering process. Winning parties are usually offered long-term purchase contracts. It is an instrument working well for well developed technologies. The exact quantity of facilitated electricity is known ex ante, but not the price for it.

Fiscal facilitation instruments aim to promote RETs by investment subsidies, low-interest loans, and different tax measures like for instance tax deduction. De Jager and Rathmann describe the main fiscal and support incentives (2008).

A detailed description of all EU facilitation strategies with their instruments can be found in Held et al. (2006) and Haas et al. (2011). The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety consolidates all regulation on RETs on a website for the EU-27[140].

For SHP in the EU-27, the HYDI database run by ESHA summarises all policy instruments[141]. Instruments can be found per country and along three categories: support (market-based and fiscal instruments), concession (water concession regulation), and legislation (all other instruments). The website is continually updated. Figure 5-8 gives the policy instruments which facilitate SHP economically in the EU.



Source: (ESHA, 2011)

Figure 5-8: Dominating policy instruments which facilitate SHP economically in the EU in 2010

With the official launch of the HYDI database, ESHA published "The current status of Small Hydropower development in the EU-27" (ESHA, 2011)[142]. This document summarises the support instruments, measures on administrative procedures and measures related to the grid, as well as the expected impact of the Water Framework Directive (WFD) on SHP. The WFD (Directive 2000/60/EC) does not make a difference between SHP and large hydro and there is incoherence between the goals of the WFD aiming at good qualitative and quantitative status of all water bodies vs. the EU RES-directives aiming at more electricity from RETs. Furthermore, administrative and regulatory barriers have to be removed and the local participation of the different stakeholders affected by a SHP project improved. Investments in R&D are necessary in order to find solutions to minimizing environmental impact at the same time as maximizing electricity production and ensuring quality. Finally, more attractive support instruments are required in some member states.

In comparison to Switzerland, most EU countries have a FIT, the equivalent of the FIR. For the economic facilitation, tenders are not currently used for SHP and fiscal incentives are partly in place, which is also the case in Switzerland (e.g., water royalty exemption for MHP). The only instrument to consider for Switzerland is the quota obligation which is discussed in Section 6.4.

[140] http://www.res-legal.de/ (accessed on 01.11.2011)
[141] http://www.streammap.esha.be/6.0.html (accessed on 01.11.2011)
[142] ESHA also published information leaflets on several subjects concerning SHP, such as the policy framework and environmental integration (SHERPA, 2008a, 2008b).

Conclusion

SHP is already well facilitated within today's institutional framework (e.g., FIR scheme, Small Hydro program). However, it is affected by much legislation (e.g., environment, energy, water, etc.) and subject to heavy administrative procedures. Many stakeholders are involved in the development of SHP and the shaping of the institutional framework with diverging opinions concerning the use and future deployment of SHP. Within the Swiss RET targets and the environmental protection objectives, the institutions have to evolve further to be aligned with the SHP technology, which is discussed in the next Chapter. Finally, this evolution has to consider the dynamics within the electricity sector as developed in Chapter 7.

6. Analysis and discussion of the alignment between small hydropower and its institutional framework in Switzerland

The previous two Chapters described the small hydropower (SHP) technology and its institutional framework. They showed that SHP has an important remaining technical potential to be developed within an adequate institutional framework. Technically well developed and economically facilitated, SHP faces mainly administrative obstacles and environmental opposition. The construction of new SHP plants in Switzerland remains largely an institutional challenge. There is a balance to find between hydropower production and environmental interests. On the one hand, additional domestic electricity production is necessary (see Section 2.2.4), including from SHP. On the other hand, streams and landscapes have to be protected as well as many have been already affected by human activities.

This Chapter analyses and discusses some of the policy instruments which facilitate the SHP development and which better align the institutions with the SHP technology, thus improving the institutional framework. The analysis is based on the qualitative research (e.g., interviews, survey, and participatory research) and the coherence framework (see Section 3.3). Some policy instruments are discussed more in detail for the Canton of Valais (the sub unit of analysis in the second part of the research; see Section 1.5 and Section 5.2.3). Additional instruments concerning storage and pumped-storage SHP are developed in Section 8.2.

Table 6-1 gives the overview of the policy instruments which are developed individually below. These instruments complete the existing ones described in Section 5.2.2. The adapted instruments are existing instruments which could be improved. The research focused more on the first two instruments.

Table 6-1: New and adapted policy instruments in Switzerland affecting SHP

Instrument	SHP specific or RETs in general	Actors[1]	Policy instrument category
Measures to simplify and harmonise the administrative procedures	RETs in general and SHP specific	Federal, Cantonal and Communal authorities	Research & Information, regulatory instrument
Efficiency criterion	SHP specific	Federal, Cantonal and Communal authorities	Command & Control instrument
Feed-in remuneration	RETs in general and SHP specific	Federal authorities, Swissgrid, Energiepool	Market-based instrument
Quota obligations with TGCs	RETs in general	Federal authorities	Market-based instrument
Labelled green electricity (green tariffs)	RETs in general	Naturemade, TÜV	Market-based instrument
CO_2 credits	RETs in general	Federal authorities	Market-based instrument
Water royalty	SHP specific	Federal authorities	Fiscal instrument
Dynamic residual flow regulation[2]	SHP specific	Federal, Cantonal and/or Communal authorities	Command & Control instrument

[1] see also Table 5-1

[2] see Section 8.2.2

Remark: The Small Hydro program is well in place and no interviewee raised the issue of adapting it at the moment. It is thus not further discussed below except for one aspect in Section 6.1.

Within the evolution of the institutional framework for SHP, an on-going debate concerns plants below 300 kW. Some Cantons (e.g., Bern[143]) and Federal actors are considering forbidding the construction of such plants. On the other hand, ISKB/ADUR strongly support such plants as there are examples of plants below 300 kW which have brought a positive environmental impact to an area, for example in the case of the rehabilitation of former mills. It is not the scope of this research to enter into the debate on plants below 300 kW as the particular focus of this research is on larger plants. However, the author is against a ban on plants below 300 kW as he believes their potential remains worth developing, especially with rehabilitation projects. They can be well integrated from an environmental perspective and they can be cost-competitive with other plants using renewable energy technologies (RETs).

6.1 Simplification and harmonisation of administrative procedures

The administrative procedures needed to obtain the various authorisations for hydropower plants are complex (see also Section 5.2). Numerous regulations, not only related the use of water, have to be considered (BFE, 2008c). The action plan of the Energy Strategy 2050 of the Federal government released following the revision of the Federal Energy Strategy post Fukushima recommends taking measures to simplify the administrative procedures for RET plants (BFE, 2011f, measure 35). This recommendation is in line with a motion passed in the Federal parliament in June 2011 which requests the evaluation of a Federal law coordinating all procedures related to RET plants as per their technology and size. If a Federal law is not possible the evaluation has to suggest other juridical changes[144]. The purpose is to optimise the procedures among the three levels of the Confederation, Cantons and Communes, as well as to optimise the cross-references between the spatial planning, environmental, water concession and construction regulations. The need also comes from the lack of coordination among the different administrative authorities. Especially more cooperation between the Cantons and the Confederation is needed (see also survey results in Appendix D), as well as more coherence amongst Cantons in applying Federal laws (Braun, 2010). The Federal parliament confirmed its intention to simplify and streamline procedures in December 2011[145]. The streamlining for SHP projects was already raised as a key priority within a survey in 2010 among the main Swiss SHP stakeholders (Programm Kleinwasserkraft, 2011).

The review of the allocation of the procedures to the different levels should include the quest to align the institutions with the technology as suggested by the coherence framework. Thus, the institutional framework (including the administrative procedures) should be aligned with SHP as a small scale and geographically distributed technology. Institutions should remain small in size, as much as possible, and within the geographical scope of the SHP technology. As the water concessions and most procedures are at the Cantonal level (see for example Figure 6-1[146]), the Cantonal level is the relevant level for many administrative procedures. In additional, Cantons ensure a regional perspective and contribute to regional ownership thus possible reducing of opposition to projects. Thus the degree of Communal authority might have to be challenged which is in line with the results of a survey on the Swiss water sector (Schaffner, Pfaundler et al., 2009). Another analysis supports this by stating that the water sector is too fragmented between the different governance levels and that the coherence between

[143] See ISKB/ADUR, “Das Kleinkraftwerk”, Nr. 77, page 14, 2011
[144] http://www.parlament.ch/D/Suche/Seiten/geschaefte.aspx?gesch_id=20103344 (accessed on 26.09.2011)
[145] The following three motions were passed on the 06.12.2011:
http://www.parlament.ch/d/suche/seiten/geschaefte.aspx?gesch_id=20113398,
http://www.parlament.ch/d/suche/seiten/geschaefte.aspx?gesch_id=20094082,
http://www.parlament.ch/d/suche/seiten/geschaefte.aspx?gesch_id=20113403 (accessed on 06.12.2011)
[146] Even in the Canton of Valais, where the water concessions are granted by the Communes, the Canton has a major role and the final decision in the granting of the concession. Therefore, the Cantons should grant the water concession (Interview VS-5). With the renewal of many concessions in the Canton of Valais, the topic of granting water concessions is going to be debated again in the coming years (Cina, Balet et al., 2011).

the levels at which the decision is made and the levels at which the decision takes effect has to be increased (Pfammatter, Zysset et al., 2007).

In the case of SHP, most of the procedures to obtain the different required authorisation are the same as for large hydropower[147]. In relative terms the transaction costs for SHP linked to the administrative procedures are thus higher per installed capacity than for large hydropower. The administrative procedures could thus be simplified and streamlined to reduce these costs.

In the case of the Canton of Valais, the duration to develop, design and get through the administrative procedures for a SHP plant is between 1-5 years[148]. For plants below 3 MW, and in case of no opposition, the duration can be reduced to 4-6 months[149]. Plants within infrastructures can generally be built more quickly than plants on streams. The procedures can thus be long. SHP project promoters have to invest without the guarantee that they will be able to build the SHP plant[150]. This uncertainty has to be reduced.

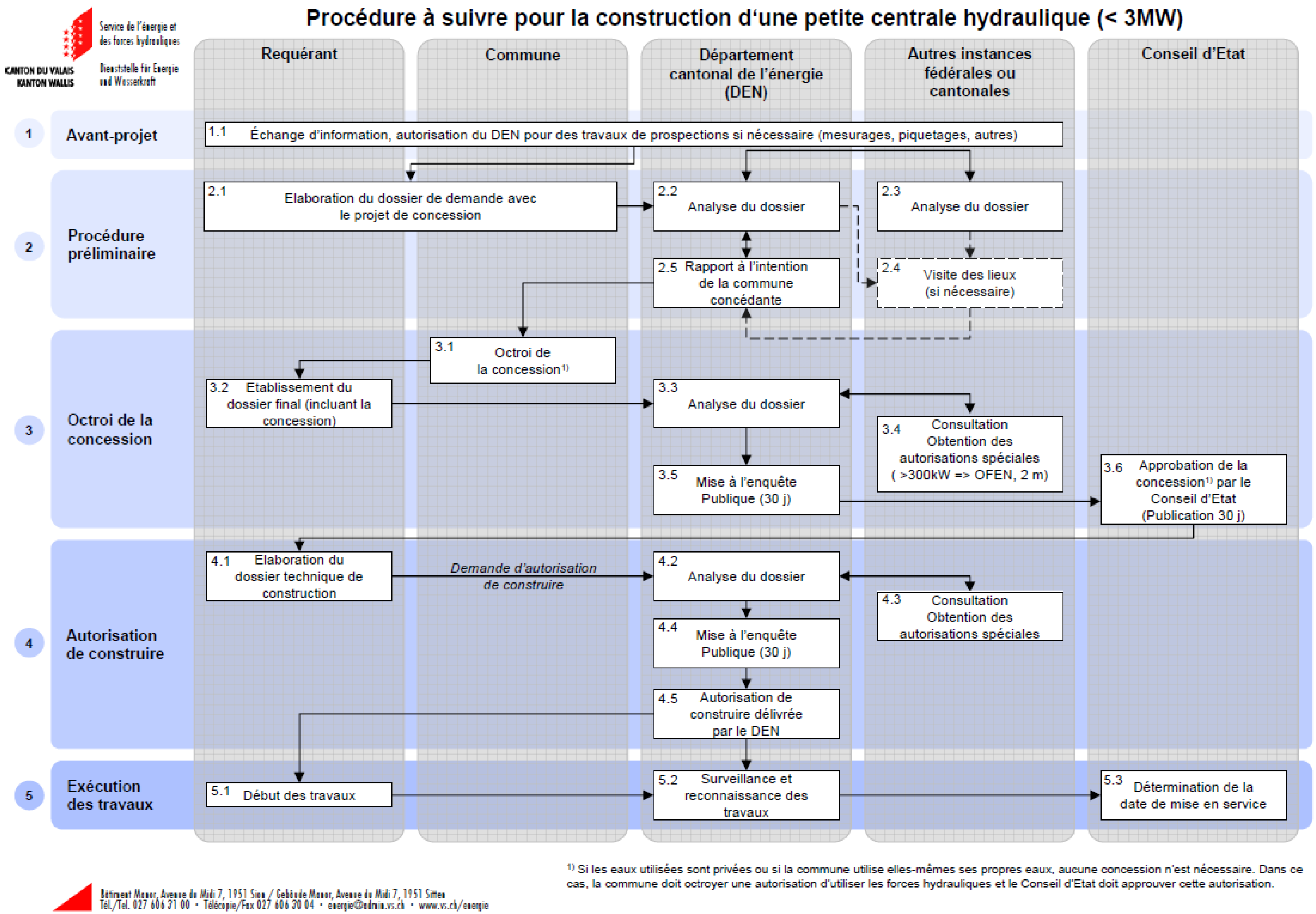
Survey questions regarding the administrative facilitation of SHP showed the following three major results (see Appendix D): Firstly, the authorisation procedures need to be simplified, especially those linked to the water concessions and construction permits. Secondly, better initial clarification is needed in order to avoid developing projects that will never be built. And finally, the coherence within the public administration and its employees concerning hydropower production and environmental protection has to be increased. Some parts of the administration support the SHP development whereas other parts oppose it. The administration as a stakeholder needs to have a common view on the balance between SHP production and environmental protection.

Simplification and harmonisation are not only an issue in Switzerland but also across the EU and in the USA. The SHAPES project strongly recommends more research on this topic for the EU (SHAPES, Mhylab et al., 2010). In the latest current status report on SHP in the EU, similar challenges to Switzerland concerning the administrative procedures are also identified in Austria, Belgium, France, Slovenia and Spain (ESHA, 2011). Obviously these are also countries (excluding Belgium) with strong hydropower potential where the institutional framework should be aligned to the SHP development.

In the USA, the administrative procedures to get all authorisations for a SHP plant are also subject to too many regulatory agencies at Federal, state, and local levels (Kosnik, 2010). This leads to fragmented, costly, and inefficient time consuming administrative procedures, and results from the use of procedures for SHP which are based on the procedures for large hydropower. Procedures must be adapted and aligned to the size of the technology.

This Section analyses some measures to simplify, harmonise and streamline procedures related to SHP. It also discusses what cannot be implemented in a near future. The administrative procedures of the Canton of Valais are given as an example in Figure 6-1. SHP projects are examined by the different services within the Cantonal administration (e.g., hydropower, spatial planning, and environment). They are approved by the Cantonal government on request of the Cantonal department of energy. The water right concession must be obtained beforehand. The concession is granted by the Communes (conceded by the Communal government and ratified by the Communal parliament) for all streams except the Rhône and Lac Léman, for which the concession is granted by the Canton (conceded by the Cantonal government and ratified by the Cantonal parliament). The procedures are complex and involve several loops to the same authorities.

[147] Interview CH-1, http://www.parlament.ch/D/Suche/Seiten/geschaefte.aspx?gesch_id=20103344 (accessed on 26.09.2011)
[148] Interviews VS-4 and VS-6. Personal communication with Interviewee VS-2, 14.01.2011. At the Swiss level it can go even up to 5 years (Leutwiler, Bölli et al., 2011: 14).
A detailed description of project development can be found in the Swiss SHP handbook (Leutwiler, Bölli et al., 2011, Section 3.2).
[149] Interview VS-2
[150] Interview CH-10



Source: in the figure

Comment: plants above 3 MW have to undergo the same procedures except that an environmental impact assessment is required instead of an environmental impact note.

Figure 6-1: Administrative procedures for the construction of a SHP plant in the Canton of Valais

Procedural bundling

Simplifying the administrative procedures could be achieved by bundling all administrative applications such as in Norway (SMART, 2009). Then the SHP promoter would not have to apply for one authorisation to use the water, another to construct the plant and finally another to connect to the grid. The promoter would compose one application to develop a SHP plant, and if the permission was granted, automatically the promoter would have the authorisation to use the water, build the power station (including the intake and the pipes) and connect to the grid. This is an effective way of evaluating an application and developing a SHP plant as a whole. Such a “one in all application” could be submitted to the Canton.

Grouped projects procedures

A further measure to simplify procedures is to deal with grouped projects (e.g., within the same sub-basin zone) or a river section (e.g., applying for a water concession for a whole section and then decide on the number and sizes of plants), instead of with single projects. This would technically optimise interlinked projects instead of focusing on single plants and could lead to the concept of virtual power plants (see Section 8.2.1). The administrative procedures would be done for the grouped projects. Furthermore, it would include better spatial planning aspects. Currently, and especially in the case of the Canton of Valais, there is no overview for the development of SHP[151]. Such spatial planning consideration would also contribute to streamline procedures as developed below.

Linear procedures

The administrative procedures could become linear and not cyclical anymore. In the case of the Canton of Valais (see Figure 6-1), three loops are done between the promoter and the administration before being able to start the construction work. It could be reduced to maximum two loops and lead to the following three phases prior to the operation of a SHP plant: 1) preliminary design[152], 2) administrative procedures and 3) construction. Thus the steps 2.1, 3.2 and 4.1 in Figure 6-1 could be merged together. This would lead to a merge of the application procedures for the water concession and the construction permit. This is moreover recommended in the Swiss SHP handbook (Leutwiler, Bölli et al., 2011) and makes particular sense if the preliminary design phase is used as a filter for the projects (see below)[153]. However, the merging of the water concession and construction permit application would require a change in the Cantonal law in the case of the Canton of Valais and would actually lead to a gain of only 30 days in the procedures[154]. It would, however, reduce the option for opposition by eliminating one procedure loop. Nevertheless, for projects which have to apply for the water concession at the Federal level, the water concession and construction permit procedures are already merged today[155], and therefore the same could be implemented at the Cantonal level.

Procedural checklists

Cantonal checklists describing all the required documents and steps to take per phase in the development of SHP projects have to be further elaborated (e.g., detail of what has to be handed in by when to whom and with which degree of details). They only exist in some Cantons (e.g., Fribourg[156], Graubünden[157], and Valais[158]). Checklists

[151] Personal communication with FMW, 22.02.2011
[152] More below.
[153] Interview VS-5
[154] Interview VS-2
[155] http://www.parlament.ch/D/Suche/Seiten/geschaefte.aspx?gesch_id=20103220 (accessed on 23.09.2011)
[156] http://www.fr.ch/shared/data/pdf/cha/potentiel_hydraulique_fd.pdf, Appendix A5 (accessed on 24.02.2012)
[157] Nine checklists exist in the Canton of Graubünden (Leutwiler et al., 2011)

have to be used by engineers, thus technical knowledge is a prerequisite[159]. Such checklists were significantly supported by the interviewees[160]. They have to be developed at the Cantonal level, especially if other simplifications lead to a concentration of all procedures at the Cantonal level. However, it makes only sense to establish such checklists for the cantons with significant remaining technical SHP potential as only a certain amount of projects justify the costs to setting up such checklists.

Administrational deadlines

Clear and binding deadlines have to be given to the authorities dealing with SHP applications (e.g., water concession, construction permit, etc.). The aim is to strive for quicker procedures[161]. It is the responsibility of the administrations to be able to meet the deadlines even though the number of projects has significantly increased since the introduction of the FIR.

Online procedures

Electronic applications could also be used to simplify procedures for SHP promoters, as was confirmed during the interviews[162][163]. All procedures could be completed online with a single web interface using standard forms. Each Canton could have its own website whilst still using the same user interface as the other Cantons. The different administrative authorities in each Canton could be assigned to the corresponding sections of the website. In addition, the application procedures for the FIR or certification procedures for labels could be included.

One-stop offices

One-stop offices at the administrations are key to facilitating SHP projects. Most Cantons have already such an office (Leutwiler, Bölli et al., 2011: 34) which is the single contact point at the administrative authorities for SHP project promoters for all the Cantonal procedures (e.g., Canton of Valais[164]). This office coordinates all procedures with the Cantonal administration. This should be put in place in every canton and even enlarged to the coordination with the communes as well.

Procedural support

The Small Hydro program already brings technical and financial support (see Section 5.2.2). However, it could be reinforced in order to provide larger advice to SHP project promoters regarding the available market-based instruments, to banks supporting SHP development and to contacts to environmental NGOs. Alternatively, the consulting service of ISKB/ADUR could be supported.

Cross country procedural harmonisation

The institutional framework concerning SHP varies between Cantons. There are even differences between Communes (BFE, 2004). Promoters of SHP projects are unable to standardise their procedures and build up their network and local knowledge for each new area they work in. A harmonisation of the institutional framework

[158] The checklist is not publically available as it is not the Canton which developed it, but the FMV. As the FMV have a role to support the hydropower development in the Canton of Valais, project promoters can ask the FMV to evaluate their project with their internal checklist which models the legislation. (Meeting FMV, 22.02.2011)

[159] Interview CH-3

[160] Interviews CH-3, CH-11, VS-4, VS-5, VS-6 and VS-7

[161] Interviews CH-3 and VS-6, meeting with EOSH committee 10.11.2011

[162] Interviews VS-4 and VS-5

[163] A recent study done by the Federal administration confirms the interest of the private sector for e-government: http://www.news.admin.ch/message/index.html?lang=de&msg-id=43435 (accessed on 17.02.2012)

[164] The Canton of Valais has such a one-stop office (Interview with Amadée Truffer, Service de l'Energie, Canton du Valais, 10.06.2010). It is the energy office which fulfils the role of the one-stop office. It receives SHP applications, gets the feedback and/or approval from the different involved cantonal offices and communicates with the SHP promoter. However, the water concession demands are treated by the communal administrations.

across the country would reduce transaction costs and lead to a more coherent SHP facilitation and development nationwide. The above mentioned motion passed in the Federal parliament in June 2011 is also along the lines of harmonisation.

Harmonisation does not just include having the same procedures at the same governance level (e.g., Cantonal level), but also a harmonised and national perspective on the development of SHP. Geographical priority areas for SHP development could be commonly defined. This could be done within Cantonal hydropower master plans as developed below.

Procedural alignment

Institutions should be coherent within themselves and with the technology. For example, a SHP plant operator received the FIR guaranteed for 25 years whereas its water concession was granted only for 20 years (see Appendix D). The time durations need to be aligned. Furthermore, they are granted water concessions which have never been used which is incoherent with SHP development[165]. A new regulation could be introduced which states that the water concession is lost if no SHP plant is built within, for example, 10 years.

Procedural streamlining of feasible projects

Finally, additional tools and methodologies are required to quickly assess projects in order to streamline procedures afterwards. With the increased number of projects following the FIR introduction the aim of such tools and methodologies is to select the feasible projects for further development and to reduce opposition by including all relevant stakeholders (e.g., environmental NGOs) in the very early phase of design. Two approaches have been identified, one at the river zone level, the other at the project level. Both approaches can be used in two ways: bottom-up to select the feasible projects based on the chosen criteria, or top-down imposing a production target for new electricity from SHP. In the latter, the approaches would be used to select the best sites and would probably need to be coordinated by river basin agencies[166].

The first approach has been initially developed by the Canton of Bern (AWA, 2010). The aim is to include the SHP development within the Cantonal master plan. The methodology consists of evaluating the hydropower potential, as well as the ecological potential and the landscape value. The outcomes are river zones where SHP development is feasible and even wished (green zone), river zones where no further SHP development is allowed (red zone) and river zones where the interests between hydropower protection and environmental protection have to be further balanced out (orange zone). For SHP projects within river zones where SHP development is feasible (green zones) no opposition could be allowed.

Inspired by this approach, the Federal administration published recommendations for Cantonal water use and protection strategies related to SHP (BAFU, BFE et al., 2011). Unfortunately, these recommendations give too much weight to the protection aspects compared to the SHP production[167]. A more detailed methodology is being developed at the University of Bern (Hemund and Weingartner, 2012) and is described in Section 4.2.2. The assessment takes into account observations on four different spatial units, i.e. region, landscape unit, riverine zone, and river section. The riverine zone assessment has to be further elaborated and included in the planning of SHP development[168]. Furthermore, such methodologies should contribute towards establishing Cantonal SHP or hydropower master plans. Such master plans were mentioned in the survey in order to facilitate SHP (see

[165] Interview VS-4

[166] The concept of river basin agencies is developed in (Pfammatter, Zysset et al., 2007) as one possibility to shape the water sector in the future.

[167] Interview CH-2, personal communication with ISKB/ADUR 2011, and opinion of the Cantons of Bern and Valais (Survey "Wasserkraftpotenzial der Schweiz", presentation of the results, SFOE, Ittigen, 14.02.2012)

[168] Interview CH-11

Appendix D). However, in Cantons where the water concessions are granted by the Communes (e.g., Valais) the elaboration of such plans remains difficult. Nevertheless, such methodological approaches to select regions for SHP development are part of the action plan of the Energy Strategy 2050 (BFE, 2011f, measure 36) and could include regional compensation schemes for the “no use” of hydropower potential as well (see Section 5.2.2).

The second approach has been developed by the Canton of Valais and consists in a tool (GigaNat) which serves as a filter for feasible projects[169]. The approach was inspired by the above methodologies. The tool is applied to the project at the beginning of the preliminary design phase, for example after or even during the pre-feasibility study[170], and before more development and engineering costs are incurred. The tool includes technical, ecological, social and economic values, and is implemented by a local expert (about 1.5 days of work). The evaluation costs about 3’000 CHF per project. The results are then discussed in a multi-stakeholder commission which decides on the final evaluation of the project. Similar to the evaluation grid of the above methodologies, projects are graded green (feasible), orange (more discussion between hydropower production and environmental considerations) and red (not feasible). This tool helps the Canton to evaluate projects today, but could also be used to streamline procedures. For example, for “green” projects the possibility for opposition could be cancelled and only the public administration would be in charge of enforcing the regulation in place on the final project. In addition, projects which have been evaluated “green” could be treated in priority within the administration for the water concession and construction permit. In this case, a notice from the authority granting the water concession would have to be included in the evaluation within the tool.

Both approaches could also be combined. The methodology leading to Cantonal master plans allows a regional perspective. The “green” and “red” zones lead to clear statements about SHP development. However, projects developed within “orange” zones could be submitted to an evaluation with a tool such as developed in the second approach, which would lead to a final evaluation of their feasibility.

In conclusion to this Section, the simplification and harmonisation of the administrative procedures related to SHP go along with having institutions which are coherent in size and scope with the SHP technology. Overall, simplification measures remain controversial. The need to simplify was confirmed with the survey and in some interviews (see measures above) and is in line with the intentions of the Federal parliament. However, many interviewees are critical on the matter[171] and the Federal council does not support a coordination law for all procedures explained above[172]. Many laws are concerned (see Section 5.2.1) and difficult to change. The procedures related to flow measurement and defining the residual flow, the procedures linked to the environmental impact, the procedures linked to the various constructions, etc. are all necessary independently of the size of hydropower plants. If procedures are cut, more opposition may rise. It is often more important to have civil servants in the various administrations who are favourable to the SHP development[173]. In conclusion, the procedures will remain the same in the near future[174]. Some procedures may be reviewed and made less detailed for example for MHP and rehabilitation projects, projects within infrastructures and for plants where the water concession comes to the end[175]. In any case, more coordination is needed within the administration at the three

[169] Meeting with Amadée Truffer, Service de l’Energie, Canton du Valais, 01.02.2011, and phone call with Andreas Zurwerra, 16.02.2011.
[170] Part of the pre-feasibility study can be financially supported by the Small Hydro Program up to 2’000 CHF (see Section 5.2.2). Investing 10’000 to 15’000 CHF is possible (Interview CH-3), which allows including an evaluation with tools such as GigaNat.
[171] Interviews CH-3, CH-4, CH-9, CH-11 and VS-2
[172] http://www.parlament.ch/D/Suche/Seiten/geschaefte.aspx?gesch_id=20103344 (accessed on 24.09.2011)
[173] Interview CH-3
[174] Interview VS-2
[175] Interview CH-2

levels. Finally, some streamlining of the procedures is possible by identifying feasible projects in the very early development phase based on multi-criteria evaluations.

6.2 Guaranteeing the technical quality of SHP plants (efficiency criterion)

Following the institutional change with the introduction of the FIR, new actors (engineering companies, construction companies, suppliers of equipment, etc.) have entered the market. These new actors do not always have the competencies to design, rehabilitate and/or construct a SHP plant thus reducing the technical quality of the plant and its performance[176]. In addition, and already before the FIR introduction, suppliers for SHP equipment did not always consider technical efficiency and performance as important. Efficiency losses above 20% could occur[177]. With reduced efficiency kWhs are lost and the economic cost-effectiveness is reduced.

Due to the set-up of the FIR scheme based on reference plants, a SHP with a weak technical design can still be economically viable if constructed at a more suitable site than the reference plant. In addition, the FIR scheme is based on the adjusted capacity which is the installed capacity adjusted by a factor linked to the annual production kWh (see Section 5.2.2). A lack in efficiency decreases the production and therefore the adjusted capacity, which increases the FIR per kWh produced. The project can remain financially viable even though the technical efficiency is below what would be technically feasible. For example, badly designed turbines or the wrong choice of pipes decrease the technical efficiency of the plant. Therefore, the FIR scheme has to be improved.

Within the FIR scheme, the only technical requirement is for rehabilitated plants (with an increase of production by 20% required to apply for the FIR (see Section 5.2.2)). Thus, there are no technical requirements for new plants.

Within the FIR regulation, the SFOE is allowed to define ecological and energetic minimum requirements within guidelines. However, it has not yet been implemented as judicial questions remain[178].

SHP plants have high investment costs but are built to last and operate for decades. Therefore, the technical quality is extremely important due to hugely expensive replacement and redesign costs. Poor quality results in reduced efficiency and frequent shut downs for maintenance, thus reducing production (Leutwiler, Bölli et al., 2011). Quality management must start with the design of the plant. However, SHP plants and especially MHP plants are too small to be developed with norms (e.g., IEC, DIN, and SIA). Such norms can be used as guidelines but are unable to be applied literally (Leutwiler, Bölli et al., 2011: 30).

From an environmental perspective, SHP plants are often better integrated into the environment if they do not use all the available flow (UVEK, 2011: 18). For each plant, the available SHP potential has thus to be used in the most optimal way from an energetic and environmental perspective (BAFU, BFE et al., 2011: 18), This leads to the right balance between electricity production and environmental protection (see Section 5.2.2 and Section 6.1). Once the head and flow to be used with the SHP plant are defined, then the technical quality and performance of the plant has to be optimised (i.e. maximise the kWh per m^3 flow through the plant). It should force actors who do not have all the required technical competencies for designing a SHP plant to acquire them from the technical specialists (e.g., Mhylab for turbine profiles).

Different instruments to guarantee the technical quality of SHP plants are analysed and discussed below. The environmental criteria and standards are accounted for when defining the head and flow. They are not part of the criteria linked to technical optimisation of the plants. Table 6-2 is an overview of the possible instruments.

176 Interviews CH-1 and CH-4
177 Personal communication with M. Chenal, ADUR, 2010 and 2011, based on the document « Prise de position concernant l'Ordonnance sur l'énergie, Octobre 2007 ».
178 Interview CH-4

Table 6-2: Instruments to guarantee the technical quality of SHP plants (chronological order during the research)

Instrument	Description	Evaluation	Sources
Technical standardisation	Some components of a SHP plant are technically standardised (mainly the electromechanical parts).	The smaller the installed capacities, the more standardisation is possible without losing too much on the technical efficiency. ABB, for example, has developed standard turbines of 150 kW[1]. Standardised components reduce investment costs. Their development triggers technical innovation for the sector and offers export opportunities. Technical standardisation does not lead to additional transaction costs from an institutional perspective. However, the development of standardised components is only economically viable if the demand on the market is big enough. Finally, standardised components reduce the technical efficiency due to a design which is generic and not site specific. Of the interviewees who expressed a view on technical standardisation, only one was in favour of it compared to six opposed. In the survey, only 16% were in favour of technical standardisation.	(Leutwiler, Bölli et al., 2011) Interviews CH-10, CH-11, VS-1, VS-4, VS-5, VS-6 and VS-7 Survey results in Appendix D
Technical standards	Technical standards for each component of a SHP plant are defined. Examples are the criteria of reliability and endurance leading to the right choice of materials. For each standard, several categories can be defined. The overall label of the SHP plant would then be a combination of the different standards thus leading to a final "grade". This grade could be linked to a label required to obtain the water concession or FIR allocation.	The standards have to be based on clear criteria. The standards would generate innovative research to meet the requirements. For plants receiving the FIR they would avoid payments to inefficient plants. However, the transaction costs (establishing criteria, introducing into regulation, auditing and monitoring, etc.) are very high and the choice of the right values to fulfil each criterion is a challenging task. The interviews showed 54% against this instrument. The favour was more towards a single global criterion. The survey results showed 83% opposed to technical standards compared to a global criterion. Large companies operating SHP plants were completely against technical standards in comparison to a single global criterion.	(Freimüller, 2010) Interviews CH-1, CH-6, CH-7, CH-9, CH-10, CH-11, VS-1, VS-2, VS-4, VS-5, VS-6, VS-7 and VS-8 Survey results in Appendix D
Single global criterion	The overall technical efficiency of a SHP plant is chosen as the single criterion for a label. The efficiency is the ratio of the electric energy fed into the grid divided by the potential energy of the water going through the water intake. A high efficiency is a good indicator of the high quality of the plant[2]. The Canton of Fribourg investigated in such a global criterion whereby the overall efficiency would have to be at least 75%[3].	A single global criterion is easily implementable combined with applying for the FIR. It could be linked to the water concession as well. There would be low additional transaction costs linked to controlling the criterion. However, the choice of the minimum criterion value would need to be further investigated and such a value would not be site specific. The interviewees strongly supported this instrument (85%). The survey confirmed this result with 83% in favour of a global criterion instead of several technical standards.	Interviews CH-1, CH-2, CH-10, CH-11, VS-4, VS-5 and VS-7 Survey results in Appendix D
Price regulation	This instrument applies only to the FIR. The remuneration values for each technology and installed capacities are	Such a FIR scheme would have added only some additional transaction costs to the scheme. It would have triggered innovation. However, the choice of the initial values	Interview CH-7

	chosen at initial values. If these values do not lead to remunerations which are high enough to develop RET plants in order to reach the RET targets, the values are increased. Thus only the most cost-efficient plants are facilitated.	would have been a challenge and it may not have excluded badly designed schemes in the beginning. As the FIR scheme has been launched without this progressive increase of remuneration, it is difficult to implement it now. Nevertheless, within the on-going review of the FIR scheme, the remuneration could maybe be adapted (see Table 6-3).	
Expert evaluation	The technical quality of the design of a SHP plant and later the construction and operation is evaluated by an SHP expert. It is combined with applying for the FIR or the water concession.	A pool of experts has to be set up (e.g., with ISKB/ADUR) which needs to be of a certain size in order to avoid a monopolistic situation of some experts. The additional transaction costs for this instrument are probably lower than with standards. This instrument is an alternative to standards as standards are difficult to define for SHP. The heterogeneity of sites is difficult to account for with standards and individual site and project evaluation offer an alternative.	(ISKB and ADUR, 2011) Interview VS-4

[1] *Personal communication, Stefan Kullander, ABB, 30.06.2010*

[2] *(BAFU, BFE et al., 2011: 18)*

[3] *(Platform Water Management in the Alps, 2011a, Appendix 2, p.33). Two other criteria were defined by the Canton of Fribourg: energy efficiency - recuperation of the energy used for the construction of the installation within <5 years, and the specific power <0.1 kW per m of head.*

Sources: in the table

When defining the instrument to guarantee the technical quality of SHP plants the aim is to have minimum additional transaction costs, avoid new legislation as far as possible and target simplicity. Based on Table 6-2, the following conclusion can be derived: Ten interviewees were in favour of introducing a new instrument to guarantee the technical quality of SHP plants and two were against it. The technical standardisation can be done on a voluntary basis by suppliers. The single global criterion is more supported than technical standards and thus further developed below. Price regulation considerations can flow into the current FIR review and expert evaluations are more appropriate in evaluating the feasibility of SHP plants (see Section 6.1 for the evaluation approach at the project level) than for the technical optimisation of the plants.

It has to be mentioned that in the survey only 24% were in favour of introducing a new label. This figure does not match with the results from the interviews and is due to the sample of the survey. The questionnaire was completed by firms who have already built their plant and receive the FIR. They do not wish additional regulation. Furthermore, only eight answers came from plants above 300 kW which are mainly considered in this research. Therefore, the survey results have to be taken into account with caution.

The chosen instrument is the single global criterion which could be linked to the available head, equipped flow and type of plants (run-of-the-river, storage, within infrastructures). For example, the more head that is available, the higher the value of the criterion would need to be[179]. This would make the criterion more site-specific which was one of the disadvantages mentioned in Table 6-2. Exceptions would be allowed for plants bringing an increased ecological value to the site.

The SFOE is currently working on such a global single criterion. However, it would have been useful to have established it before launching the FIR scheme in order to avoid new SHP plants supported by the FIR but designed or built with poor technical quality.

[179] Interview CH-6

The global single criterion can also be seen as an “energy label”. Today, energy labels exist at the consumption level (e.g., fridge, washing machine, energy label for buildings), but not at the production level. Based on the inverse concept of minEnergy label for buildings[180], which aims at the lowest consumption, the energy label for SHP plants would aim at the maximisation of electricity production for a given head and flow.

Regarding the question linking the global single criterion with the FIR or water concession application, the interviewees were clearly in favour of linking it with the concession application[181], as were the survey results with 80%. Therefore, a SHP project applying for the water concession would have to fulfil the value of the criterion given for its head, flow and type of plant. The value could be controlled at the beginning of operation and monitored every five years. However, the value could not be changed retroactively. If the value is not fulfilled, the plant owner is obliged to improve the plant’s efficiency.

Rehabilitated plants would therefore not be concerned if the water concession remained unchanged. Nevertheless, most rehabilitated plants apply for the FIR and already have to increase their production on the given site. An instrument for guaranteeing the technical quality in these cases is less important.

However, the implementation of the global criterion with the water concession is complicated, as the regulations are not harmonised across the country. Furthermore, as guaranteeing the quality is mainly linked to the FIR, it is suggested to link the implementation of the global criterion with the FIR regulation[182]. In a later stage, if the regulation linked to the water concessions is changed, the criterion could be linked with the water concession.

6.3 Feed-in remuneration

The introduction of the FIR was a significant step towards the facilitation of RETs and boosted the SHP development. The FIR scheme is the main market-based instrument for the institutional facilitation of SHP in Switzerland. In its initial stage, it had some problems which have already been dealt with (e.g., well maintained and rehabilitated plants could not receive the FIR, projects could apply even though the water concession would never be obtained, and lack of funding[183]). Further problems are listed in Table 6-3. The FIR scheme remains in revision by the Federal parliament and the SFOE.

During the first part of the research, several other actors were identified who worked to improve the FIR scheme (see right column in Table 6-3). Therefore, this research did not focus on contributing significantly towards the evolution of the FIR with the exceptions of the adaptation of the scheme to storage and pumped-storage SHP for peak electricity production (see Section 8.2.1) and the technical quality guaranteed (see Section 6.2).

[180] http://www.minergie.ch (accessed on 26.09.2011)
[181] 4 interviewees: link with concession
1 interviewee: link with FIR
2 interviewees: link with both
[182] Meeting with Bernhard Hohl, SFOE, 11.10.2011
[183] Since March 2012, an alternative to the FIR is the green electricity exchange market (http://www.oekostromboerse.ch/) through which projects can be funded.

Table 6-3: FIR problems and possible solutions

FIR problem	Solution suggestion	Actors engaged for the solution
The initial applied **differentiation for the different FIR** is not enough to account for the strongly differing characteristics of the SHP plants, including the difference for expanded or renewed plants (Manser, 2011).	**Adapt the remuneration curves** (see second-best choice in (Manser, 2011: 67)). On average, the effective FIR paid in 2010 was over what was required per plant to be economically viable with an IRR of 5%. However, the adaptations might involve a long and costly process, thus not be implemented.	SFOE
The FIR scheme lacks certain provision for **low-head sites** (Leutwiler, 2008).	**Adapt** the remuneration scheme, i.e. the **bonus on the head** (introduce additional differentiation below 5 m). Low head SHP plants represent most of the remaining potential of run-of-the-river plants and many existing plants could be rehabilitated. The institutional facilitation has to be coherent with the available technological options.	ISKB/ADUR
The **FIR scheme is static** and does not take into account changes in tax schemes. E.g. when the water royalty is increased affecting SHP above 1 MW, the FIR is not adapted automatically.	**Modify the FIR scheme to be dynamic** in order to take into account any modification of federal tax schemes over the time period of the FIR payment. Institutions have to be coherent in themselves and evolve together over time.	ADUR
Some plants are not **cost-efficient** and receive FIR even though they have investment costs above 100'000 CHF/kW (Manser, 2011). More cost-efficient plants are stuck on the waiting list.	**Introduce minimum cost-efficient standards** per SHP category (run-of-the-river, drinking water, etc.). Alternatively, the application list for FIR could be changed from chronological order (initially) to granting the FIR by a merit considering the most cost-efficient plants first during a given period of time. A further alternative evaluated by the government is to grant FIR to large plants in priority.	SFOE
The **energetic optimisation** of a site is not considered enough. This is partly due to the rush on the FIR due to the limited funding. Once the FIR is allocated, technical modification of the installed capacity is limited (see Section 5.2.2). In addition and in order to get higher remuneration per kWh, a site can be split into several smaller projects instead of one project using the technical potential in an energetically optimal way.	**Introduce a label** or other measure to guarantee the technical quality of SHP plants (see Section 6.2). Technical performance should be as high as possible as consumers finance the FIR scheme and do not wish to support badly designed plants.	SFOE, ADUR
Energiepool who is in charge of the FIR payments does not respect the **payment deadlines**. The MKF is paid monthly with a payment term of 30 days; the FIR is paid every 3 months with a payment term of 60 days. Even this term is not respected[1].	Energiepool has to **pay on time** the FIR.	ISKB/ADUR, SFOE

The **VAT** was added at the end of the FIR design process without further consultation of the different stakeholders. MKF has no VAT. The issue was treated by the Federal Administrative Court which rejects the removal of the VAT from the FIR scheme.	**Add the VAT to the FIR** and make the FIR dynamic in order to adapt tariffs directly when the VAT is changed.	-
Customers paying for labelled electricity pay as well for the FIR. They are therefore **charged twice** – once to be supplied from RETs themselves (label) and once to support RETs development (FIR). Therefore they don't have any personal benefit from paying for the FIR.	Customers buying labelled electricity have to **be exempt from paying for the FIR.**	Naturemade-VUE

[1] *Several interviewees mentioned this fact. E.g., an interviewee operating several plants had not only payment delays, but wrong adjustments from Energiepool between different years. As the FIR is paid taking into account the yearly production, the first payment of the year takes into account the final accountability of the previous year. In 2010, Energiepool mixed the difference of 2009 thus instead of paying the difference to the interviewee's business subtracted the difference from the first payment. (Interview VS-5)*

Sources: from the interviews and in the table

Finally, it has to be mentioned that some stakeholders within the hydropower sector suggest using the FIR to finance rehabilitation and/or upgrading of large hydropower plants[184]. The argument is that in some cases and with measures having no or almost no impact on the environment, the efficiency gains lead to an amount of renewable kWh which can be significantly bigger than the production of many MHP plants having an impact on the environment. This suggestion remains a topic within the on-going revision of the FIR scheme.

6.4 Quota obligation with TGC

Another main market-based instrument to facilitate RETs is the introduction of quota obligations as described in Section 5.2.4. It has to be noted that these obligations are not linked to the labelled green electricity market described in Section 5.2.2 and further developed in the Section 6.5.

The quota obligation scheme with tradable green certificates (TGCs) can be introduced if the FIR does not fund all remaining technically and ecologically feasible projects or if the economic facilitation solely with the FIR scheme does not reach the RETs target set by the government (see Section 2.2.3 and 2.2.4). However, with the adaptations of the FIR scheme, mainly the increased funding as mentioned in the Section 5.2.2, the RETs target should be reached and the remaining technically and ecologically feasible projects built. Therefore, there may be no need to introduce the quota obligations which would add further administrative procedures and thus increase transaction costs.

The Energy Law foresees a quota obligation scheme with TGCs which could be introduced by 2016 (2011, Art. 7b al. 4). The action plan of the Energy Strategy 2050 of the Federal government includes a measure considering the introduction of a quota obligation scheme with TGCs for well developed RETs (BFE, 2011f, measure 34). As SHP is already well developed, this could be a technology covered by the scheme.

If it is introduced, the following main questions will have to be addressed in designing such a scheme:

- Should the market be designed as a Swiss TGC market or linked with the EU market?

[184] Workshop "Energiestrategie 2050: Wasserkraftpotenzial der Schweiz", Bern, 15.11.2011.

- What is the duration of the TGC scheme?
- What will the penalty be for not reaching the quota?
- Is the banking of certificates between years possible?
- Are there any sub-quotas per RET or are the certificates from different RETs given different weights (e.g. for 1 kWh from photovoltaic 3 certificates, but for 1 kWh from SHP 1 certificate)?
- Are existing plants eligible?

An overview of the quota obligation and TGC schemes for EU countries can be found in Haas et al. (2011, Table 4). The author did not develop it further as in his opinion the FIR scheme facilitates enough RETs and SHP. Furthermore, a study for the SFOE suggests not to mix both schemes (Ernst Basler + Partner, 2009).

6.5 Labelled green electricity (green tariffs)

On a global scale, 71% of fossil-fuel related and direct greenhouse gas emissions can be attributed to the activities of urban areas (Keirstead and Schulz, 2010) and about 70% of the world's primary energy consumption arises from cities (IEA, 2008). The policy choices of urban areas such as cities influence greatly future developments in climate change mitigation and in the energy sector. One observable trend is that the demand for labelled green electricity from RETs (e.g., Naturemade and TÜV labels; see also Section 5.2.2) is increasing mainly from distributors in cities, but even Cantons are considering purchasing only labelled green electricity for their administrations. Major Swiss cities (e.g., Geneva, Zürich, Bern, Lausanne, etc.) have stopped or will stop purchasing electricity from nuclear power plants and will distribute electricity mainly from RETs. Furthermore, the movement "Covenant of Mayors" adds to the demand for labelled green electricity. This movement involves local and regional authorities to voluntarily commit to increase energy efficiency and the use of RETs in their territories[185]. By their commitment, Covenant signatories aim to meet and exceed the European Union 20% CO_2 reduction objective by 2020. Several Swiss city municipalities joined the movement[186].

The Fukushima disaster has not significantly changed the purchase of labelled green electricity by private consumers. For a few months, the demand increased but then fell back on previous growth average[187]. There is a slow growth in the demand for labelled green electricity, but the production of labelled green electricity substantially surpasses the demand (see Table 6-4). Nevertheless, some of the labelled electricity is sold in bilateral contracts and does not appear in the statistics of the organisation in charge of the Naturemade label[188].

Table 6-4: Naturemade electricity – produced and sold in April and September 2011

Date: 12.04.2011	Production (GWh/year)	Sell (GWh/year)
Naturemade Star	1'796	783
Naturemade Basic	7'626	1'796
Date: 13.09.2011	**Production (GWh/year)**	**Sell (GWh/year)**
Naturemade Star	1'968	780
Naturemade Basic	8'837	1'856

Source: http://www.naturemade.org/Franz/Label/label_f_aktuell.htm (accessed on 12.04.2011 and 27.09.2011)

185 http://www.eumayors.eu/index_en.html (accessed on 27.09.2011)
186 Updated list on: http://www.eumayors.eu/about/signatories_en.html?q=&country_search=ch&population=&date_of_adhesion=&status=
187 Tages Anzeiger, Brönnimann, C. (2011) "Der "Fukushima-Effekt" flacht ab", 21.06.2011.
188 Personal communication with VUE naturemade, 27.09.2011.

Green tariffs are a voluntary instrument which facilitates RETs. In the case of the label “Naturemade star”, it leads to an additional ecological value for SHP plants which allows remuneration from green tariffs on the market [189]. However, not many SHP plants are labelled “Naturemade Star” or “Naturemade Basic” (see Section 5.2.2). The main reason for the low number of labelled SHP plants, even before the FIR introduction, are the high administrative costs, i.e. transaction costs, which go from 0.56 up to 1.64 cts/kWh (PSI, 2005: 117).

To further improve the Naturemade label for SHP and in order to reduce the transaction costs, several projects could be bundled together and apply as a package for the label based on the idea of “programmatic CO_2-credits” (see next Section).

Labelled electricity is in direct competition with the FIR scheme. Consumers already paying for the FIR (see Section 5.2.2) may not understand why they should pay additionally for labelled green electricity (see Table 6-3). If there is significant additional funding for the FIR scheme, the author sees a future for green tariffs only within public administration. However, once the FIR scheme expires, green tariffs could become an alternative market-based instrument to facilitate RETs, combined with quota obligations.

Finally, it has to be mentioned that because of the labelling a whole new industry of certification and of certificates trading emerged. This industry adds costs to the electricity production costs of RETs. There are some cases where money is gained just by trading certificates without adding any single kWh in production[190]. This has to be questioned from a RETs facilitation perspective.

6.6 CO_2 credits

The future climate institutional framework remains filled by uncertainties. The Kyoto protocol regulates climate policies until 2012. Following COP17 in Durban, it will now be possible to continue the Kyoto protocol beyond 2012 without any gaps in its implementation[191]. According to the resolution passed in Durban, the negotiations for a legally binding climate protection agreement shall be concluded by 2015 with the agreement becoming effective from 2020. This affects Swiss policy making.

New thermal plants in Switzerland, e.g. gas-fired combined cycle (GCC) plants, will not be operational before 2013. It is therefore in a post-Kyoto context that such plants will need to compensate their GHG emissions. In January 2011, the ordinance on CO_2 compensation for fossil-thermal power plants became effective [192]. 70% of the compensation has to occur nationally. The minimum technical efficiency for new sites is 62% and for existing sites 58.5% (e.g., Chavalon). However, the lower chamber of the Federal parliament suggested in their summer session 2011 that if nuclear power plants are taken from the grid before 2020, thermal power plants would have to compensate only 20% of their emission nationally instead of 70% initially[193]. The compensation scheme continues to be reviewed.

In 2011, the Swiss government started negotiations with the EU to merge the Swiss emission trading scheme (ETS) with the EU ETS by 2013[194]. A report on the topic requested by the Federal administration shows that such a merger is slightly favourable for Switzerland (First Climate and Econability, 2009). The merger would allow Switzerland to obtain cheaper certificates on the EU ETS for CO_2 compensation.

[189] E.g. http://www.topten.ch/deutsch/oekoenergie/oekostrom/wasser.html (accessed on 27.09.2011)
[190] Personal communication with Interviewee CH-1
[191] http://www.bafu.admin.ch/dokumentation/medieninformation/00962/index.html?lang=en&msg-id=42645 (accessed on 12.12.2011). Even though not all countries which signed the initial Kyoto protocol will continue (e.g. Russia, Canada, Japan).
[192] http://www.admin.ch/ch/d/sr/641_713/index.html (accessed on 03.02.2012)
[193] http://www.parlament.ch/d/mm/2011/Seiten/mm-urek-n-2011-06-21.aspx (accessed on 27.09.2011)
[194] http://www.bafu.admin.ch/emissionshandel/10923/index.html?lang=de (accessed on 02.12.2011)

The current compensation scheme does not allow use of RETs producing electricity, except biomass, for CO_2 compensation (BAFU and BFE, 2008). Therefore, SHP cannot currently contribute to the Swiss ETS and CO_2 compensation scheme by generating CO_2 credits. This is not coherent. A clear majority of the interviewees is in favour when asked whether SHP should be part of the CO_2 compensation scheme[195].

The most advanced GCC plant in Switzerland is Chavalon with an installed capacity of 400 MW and a production of 2.2 TWh per year. The plant could become operational in 2017. The plant would emit 750'000 t of CO_2 per year[196], which corresponds to 340 gCO_2/kWh. Taking a general average of 480 t of CO_2 avoided per 1 GWh produced with SHP (ESHA, 2006), 1'560 GWh of SHP would compensate Chavalon. This amount accounts approximately for the remaining SHP potential (see Section 4.2.2). Thus, if SHP was part of the CO_2 compensation scheme and several GCC plants were built in Switzerland, the compensation could facilitate more than the remaining SHP potential without the need of the FIR.

The compensation scheme currently aims more at measures within the building and transport sector than RET for electricity production. Yet, if more electrical cars are introduced in order to reduce the CO_2 emissions, then the additional electricity should come as much as possible from RET to substitute completely the fossil fuel. Therefore, the CO_2 compensation scheme should also facilitate the production of the additional electricity from RETs, for example with CO_2 credits for RETs, including SHP.

To reduce transaction costs for CO_2 credits for SHP plants, and therefore align better the size of procedures with the size of the technology, programmatic credits (Africa Progress Panel, 2009) could be developed instead of certifying each single plant. Several SHP size categories and type categories (run-of-the-river, storage, within infrastructures) would be defined and accredited a certain amount of CO_2 credits per produced kWh. New plants could refer to these categories and be allocated their CO_2 credits thus reducing administrative procedures and costs.

If RETs, excluding biomass, cannot generate CO_2 credits, then instead of increasing the amount paid by the customers per kWh to finance the FIR, the latter could also be financed partly through the CO_2 compensation scheme. A given amount of CHF per t of emitted CO_2 would be paid into the FIR fund by the GCC plant operators. The FIR payment of electricity consumers would not have to be increased.

In summary, all RETs should be included in the CO_2 compensation scheme. Gas power might replace nuclear power and cover part of the increasing demand. To do so, they should be able to compensate their CO_2 emissions with RETs producing electricity.

Finally, in the on-going climate negotiation, technology transfer represents a key topic. SHP as a technology for developing countries offers exportation opportunities for the Swiss hydropower industry and could be further facilitated by generating CO_2 credits under improved and post-Kyoto “Clean Development Mechanisms (CDM)”. This could be part of the CO_2 compensation of Swiss thermal plants[197]. Multipurpose SHP plants with flood protection in developing countries would be an example of both a climate adaptation and mitigation measure generating CO_2 credits for Swiss GCC plants.

[195] In favour: CH-1, CH-2, CH-11, VS-5, VS-6, VS-7. In favour with specific conditions: CH-9
[196] http://www.chavalon.ch/de-CH/homepage
[197] Remark: In the current Kyoto framework, no storage facilities are allowed for SHP plants which want to get CO_2 credits under CDM. This has to be reviewed in light of Chapter 7.

6.7 Water royalty

This instrument concerns only the better alignment between institutions and the SHP technology. It does not facilitate SHP.

The water royalty has been described in Section 5.2.2. The use of water for hydropower is taxed. This should be independent from the installed capacity. One interviewee was therefore in favour of eliminating the exemption for MHP and the reduction for SHP below 2 MW if, at the same time, the FIR was adapted accordingly to cover the water royalty costs[198]. As the Swiss FIR is called “cost-covering remuneration”, it should cover all costs related to SHP and therefore include the water royalty.

Over the past years, various adaptations of the water royalty scheme have been discussed. Among them and for plants with high initial investment costs, the option of a reduced royalty at the beginning of the concession time when a plant operator has to write off its investment was discussed. The royalty would then increase over the concession time and reach higher values than the legal maximum after the amortisation period in order that the average royalty over the concession time corresponds with the legal maximum (BFE, 2008c). Furthermore, the evolution from the water royalty to a resource rent continues to be studied and some suggestions can be found in Banfi and Filippini (2009) and Leimbacher (2008: 43).

Finally, the use of water is supposed to be taxed, not the potential power. Therefore, if the government wants to tax the use of water for producing electricity, it should put a tax on the produced kWh (Plaz and Hanser, 2008, Section 4.4). This would as well acknowledge the difference between storage and run-of-the-river plants. The water royalty will continue to be debated and is likely to be reviewed in a near future.

6.8 Comparison and synthesis of the policy instruments

The analysed instruments of this Chapter are compared along with their possible interlinking and the implications in changing the legal regulation. Table 6-5 shows which instruments exclude each other or which can be interlinked. Measures to simplify and harmonise the administrative procedures can be combined with most other instruments. The efficiency criterion cannot be interlinked with green tariffs, neither can the FIR. A quota scheme does not interlink with green tariffs or CO_2 credits. In case of a CO_2 compensation scheme combined with partly funding the FIR scheme, CO_2 credits would be linked with the FIR. The FIR could also be interlinked with dynamic residual flow regulation as developed later in Section 8.2.2. The same accounts for green tariffs.

[198] Interview CH-2

Table 6-5: Policy instruments excluding each other (dark grey) and which can be interlinked (light grey)

Policy instrument	**Measures to simplify and harmonise admin. procedures**	**Efficiency criterion**	**FIR**	**Quota with TGCs**	**Green tariffs**	**CO_2 credits**	**Water royalty**	**Dynamic residual flow**
Measures to simplify and harmonise admin. procedures								
Efficiency criterion								
FIR								
Quota with TGCs								
Green tariffs								
CO_2 credits								
Water royalty								
Dynamic residual flow								

Table 6-6 compares the instruments on whether Federal or Cantonal laws have to be adapted (excluding ordinances). Changes in the laws regarding the administrative procedures are difficult to implement in the short term. On the other hand, some laws related, for example, to the market-based instruments are going to be reviewed anyway and thus some changes are more easily implementable (e.g., for the FIR and CO_2 credits).

The efficiency criterion can be introduced without changing the law, but in adapting the Energy Ordinance (or Cantonal regulation if introduced linked to the water concession). In the case of the FIR, some adaptations require changes in the law (e.g., increasing the amount for SHP within the available funding), whereas others not (e.g., changing the remuneration values).

Table 6-6: Policy instruments and changes in the law (in order of appearance in Chapter 6)

<table>
<tr><th>Instrument</th><th>No changes in the law required</th><th>Changes in the law required</th></tr>
<tr><td>Measures to simplify and harmonise administrative procedures</td><td></td><td></td></tr>
<tr><td>Bundling of all applications for the various authorisation to 1 application</td><td></td><td>X</td></tr>
<tr><td>Grouped projects apply together for the various authorisations</td><td></td><td>X</td></tr>
<tr><td>Simplify procedures depending on installed capacity and type of plant</td><td></td><td>X</td></tr>
<tr><td>Linear procedures</td><td></td><td>X</td></tr>
<tr><td>Procedural checklists</td><td>X</td><td></td></tr>
<tr><td>Clear and binding deadlines for the administration</td><td>X</td><td></td></tr>
<tr><td>Electronic procedures</td><td>X</td><td></td></tr>
<tr><td>One-stop office for all administrative procedures</td><td>X</td><td></td></tr>
<tr><td>Reinforce the Small Hydro program</td><td>X</td><td></td></tr>
<tr><td>Cross country procedural harmonisation</td><td></td><td>X</td></tr>
<tr><td>Procedural alignment</td><td>X</td><td></td></tr>
<tr><td>Methodologies to evaluate SHP potential with a holistic approach (and if possible leading to Cantonal master plans)</td><td>X</td><td></td></tr>
<tr><td>Tools to evaluate the feasibility of SHP projects at a very early stage</td><td>X</td><td></td></tr>
<tr><td>Efficiency criterion for SHP plants (with FIR)</td><td>X</td><td></td></tr>
<tr><td>FIR: adaptations</td><td colspan="2">X</td></tr>
<tr><td>Quota with TGCs</td><td>X</td><td></td></tr>
<tr><td>Green tariffs: adaptations</td><td>X</td><td></td></tr>
<tr><td>CO_2 credits for SHP plants</td><td></td><td>X</td></tr>
<tr><td>Water royalty: adaptations</td><td></td><td>X</td></tr>
<tr><td>Dynamic residual flow</td><td></td><td>X</td></tr>
</table>

As a synthesis, the following can be noted:

- **Measures to simplify and harmonise administrative procedures:** Some measures requiring changes in the law are to be evaluated, further developed and eventually implemented in the long term, such as the procedural bundling, grouped projects applications and the simplification of procedures depending on the installed capacity and type of plant. This could be done combined with striving for linear procedures and procedural harmonisation across the country. The evaluation will be done by the Federal administration following the acceptance of a motion in June 2011 (see Section 6.1).
  Other measures could be implemented immediately, such as the increase of electronic procedures, reinforcement of the Small Hydro program, one-stop offices in the Cantons where they do not yet exist, and alignment of concession durations to FIR allocation durations. In Cantons with important remaining technical potential checklists could be edited.
  Finally, methodologies and tools to evaluate SHP potentials and projects could be developed nationally in order to have harmonised perspective and defined priority regions on the SHP development (including compensation schemes for the “no use” of hydropower potential). In addition, such methodologies and tools can be applied as filters to identify the feasible SHP projects in the very early stages of development.
- **Efficiency criterion:** A single global criterion could be introduced combined with the FIR guaranteeing the technical quality of SHP plants. No new law is required.

- **FIR:** The scheme is undergoing some changes and the SFOE has the lead to improve the FIR scheme for SHP. Some considerations concerning the remuneration of storage and pumped-storage SHP schemes are developed in Section 8.2.1.
- **Quota with TGCs:** TGCs and quotas would add complexity to the institutional facilitation of SHP and are currently not necessary to economically facilitate SHP as more funding for the FIR scheme will become available. However, they could become the alternative market-based instruments once the FIR scheme is finished.
- **Green tariffs:** Such tariffs will probably be paid more and more by public administrations, mainly municipalities, purchasing their electricity from RET plants. Private customers already pay their FIR contributions per kWh to facilitate economically RETs.
- **CO_2 credits:** The legislation is currently being established. SHP plants should benefit from CO_2 credits in order to contribute to the CO_2 compensation of gas-fired power plants, i.e. compensate emissions generated by electricity production from fossil plants by CO_2 credits generated by electricity production from RET plants.
- **Water royalty:** If an aim in the electricity sector is to have transparent costs, then the water royalties would have to be adapted to all installed capacities and paid on the consumption of water. SHP would therefore have adapted water royalties depending on the installed capacity or annual production. The FIR scheme should then cover the water royalty costs in order to remain a cost-effective remuneration scheme.
- **Dynamic residual flow**: Adaptations to the existing residual flow regulation remains difficult. The topic of dynamic residual flow is a long debated one. Section 8.2.2 develops the topic into more details.

Conclusion

The institutional framework has to be further aligned to the SHP technology. As a next step, the administrative procedures are going to be reviewed at the Federal, Cantonal and Communal level. Communes may lose some degree of autonomy allocated to the Cantons. Independently to the changes, and in the nearer future, more coordination is required among the administration at the three governance levels. Furthermore, harmonisation across the country will be achieved by the same procedures in the different Cantons and a common view on the development of SHP and environmental protection within public administration. Finally, priority regions and/or river basins for SHP development have to be defined in a multi-stakeholder approach taking into account spatial planning, landscape and environmental protection, as well as climate mitigation and RET targets.

Among the analysed policy instruments, the introduction of an efficiency criterion for SHP plants receiving the FIR is suggested. Furthermore, SHP plants should be able to generate CO_2 credits in order to compensate emissions from future GCC plants.

The future institutional framework concerning SHP will depend as well on the further deployment of large hydropower. Should large hydropower projects become again more environmentally and socially acceptable in Switzerland, then the RET targets might be reached with smaller contributions from SHP. The societal debate will show if the preference lies with a multitude of SHP plants, which should and can be well integrated environmentally, or with a few large hydropower plants, or a combination of both. In any case, the facilitation of SHP should not hinder the development of large hydropower.

In addition to the above instruments, some further instruments are analysed and discussed in Section 8.2 which concern the storage and pumped-storage application of SHP. Storage and pumped-storage SHP is introduced in the next Chapter.

7. Storage and pumped-storage small hydropower

Storage and pumped-storage hydropower are proven technologies to efficiently provide flexible electricity production and balance the grid, as well as to contribute to energy storage. Pumped-storage hydropower is today one of the most efficient and flexible large scale means of storing electric energy. The small scale application of storage and pumped-storage hydropower still has to be developed. Such small hydropower plants can be developed on streams and within infrastructures. Their potential is worth being evaluated and developed within the facilitation of RETs.

This Chapter starts with briefly introducing energy storage technologies and describes storage and pumped-storage hydropower. Section 7.2 explains the arguments to develop storage and pumped-storage SHP (S&P/S-SHP) within the dynamics in the electricity sector. In order to evaluate the technical potential of S&P/S-SHP, an assessment methodology has been developed and is presented in Section 7.3. The results of the technical evaluation follow and are analysed in Chapter 8, as well as the institutional framework for S&P/S-SHP development.

7.1 Energy storage and hydropower

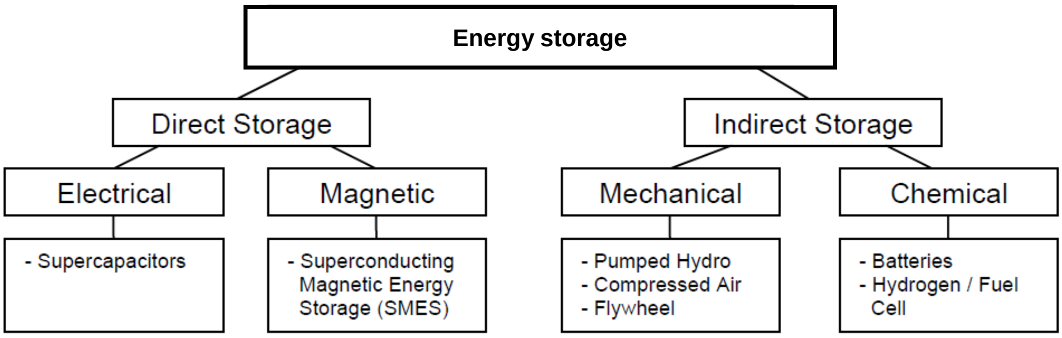
The various energy storage technologies are introduced in this Section and storage and pumped-storage hydropower is described in more detail.

7.1.1 Energy storage and flexible production

Energy storage can occur at the different steps within the electricity supply chain[199]: at the production (e.g., storage hydropower), at the distribution (e.g., fuel cells) and at the customers (e.g., batteries in electrical vehicle). Storage solutions can be found anywhere between the large scale level to the household level.

Energy storage technologies can be differentiated along several parameters such as installed capacity, stored energy, energy density, maturity, geographical dispatchability, portability, costs, response time, efficiency, lifetime, environmental impact, etc. It is beyond the scope of this research to compare the technologies in detail. Some of the main technologies are described briefly below (alphabetic order)[200]: The technologies can be divided into direct storage (electric and magnetic storage) and indirect storage (mechanical and chemical storage) as shown in Figure 7-1.

[199] Electric energy itself cannot be stored, but has to be transformed into another type of energy.
[200] Literature on energy storage technologies includes (Naish, McCubbin et al., 2008; Nekrassov and Prestat, 2010) and http://www.electricitystorage.org (accessed on 10.08.2011).



Source: (Zach, Auer et al., 2012)

Figure 7-1: Overview of energy storage technologies

- **Batteries**: These are electrochemical devices that convert electric energy into chemical energy during charge and convert chemical energy back into electric energy during discharge. There are various types such as lead-acid, sodium-sulphur, lithium, nickel, zinc-bromine, metal-air and vanadium redox batteries. The different types have different technical properties and inherent costs. Batteries can be used for energy storage and power quality control (e.g., voltage and frequency control).
- **Compressed air energy storage (CAES)**: Air is compressed into either an underground structure (e.g., a cavern, aquifer, or abandoned mine) or an above ground system of tanks or pipes. During electricity generation, the compressed air is mixed with natural gas, burned, and expanded in a modified gas turbine. Currently, only two commercial sites exist (Uniyal, 2010). On-going research is developing adiabatic CAES systems in which the heat of compression is stored and then reused to heat the compressed air before expansion thus mostly eliminating the use of natural gas in the system. CEAS is used for energy storage.
- **Flywheel**: The electric energy is stored as kinetic energy in a rotating wheel or cylinder. The stored energy is proportional to the moment of inertia and to the square of the rotational velocity of the flywheel. In order to reduce friction with the air and thus increase efficiency, the flywheel operates in a low pressure environment. There are high speed flywheels, which are small and light, and low speed ones, which are large and heavy. Flywheels are used for power quality control.
- **Fuel cell**: The most common fuel is hydrogen. Hydrogen storage is made of an electrolyser unit which generates hydrogen to store electricity. Hydrogen is compressed and stored. The fuel cell converts the hydrogen back into electricity and is used for energy storage.
- **Pumped-storage hydropower**: see next Section. It is used for energy storage and power quality control.
- **Super capacitors**: Also known as Electrochemical Capacitors (EC), super capacitors store electric energy in the electric field between a pair of charged plates. They contain a significantly enlarged electrode surface area compared to conventional capacitors. Super capacitors are used for specific applications requiring the delivering of high power during short periods.
- **Superconducting Magnetic Energy Storage (SMES)**: SMES store electric energy in a magnetic field by circulating a DC current through a cooled superconducting coil. The coil is cooled beyond its super-conduction temperature thus making the resistance of the material to electric current disappear. SMES is used for energy storage and power quality control.

In addition, there are various types of thermal storage such as using molten salt schemes. Furthermore, new and small scale storage technologies are being developed such as hydropneumatic storage.

Besides energy storage, flexible production is required to operate the grid (e.g., power quality control). Flexible production needs to include programmability, dispatchability, and quick response times. Variability and uncertainty are known aspects within the electricity sector. The need for flexible generation to balance the production and demand is not a new challenge. However, the fluctuation will continue to increase due to the deployment of intermittent RETs and thus require more flexible production. Such production can be combined with storage facilities (e.g., pumped-storage hydropower).

7.1.2 Storage and pumped-storage hydropower

Storage hydropower plants only use natural inflows[201]. They have an upper reservoir which can store water up to a maximum level given by the technical characteristics of the site. They can provide flexible production and "store" electricity by not producing, thus storing the water, while, for example, other RETs feed into the grid. The storage capacities allow, among other things, the shifting of production from periods with high rainfall to periods with low rainfall.

Pumped-storage plants have both an upper and lower reservoir (see Figure 7-2), which have minimal and maximum water levels. When the electricity prices are low or there is a need, for example for negative power balancing, the water is pumped up from the lower reservoir. During demand and price peaks, or when there is a need for positive power balancing, the water is released through the turbine from the upper reservoir. Up to more than 80% of the energy consumed during the overall cycle can be recovered, which means that 100 kWh stored delivers more than 80 kWh at peak time.

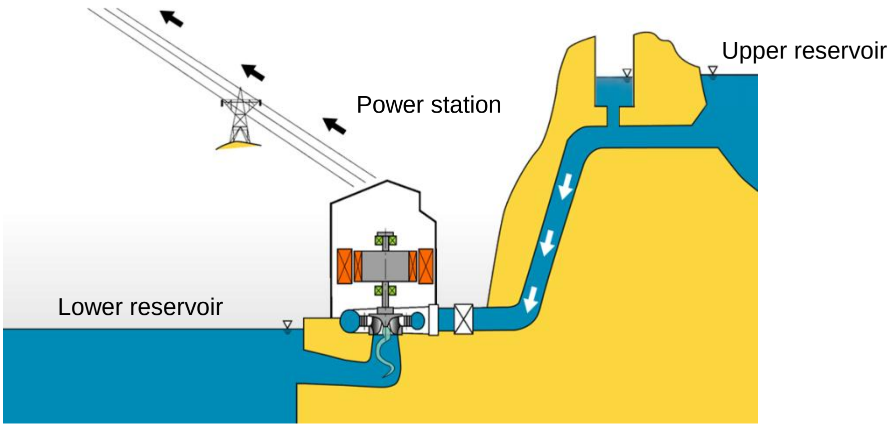


Figure 7-2: Pumped-storage plant in turbine mode

Storage and pumped-storage hydropower plants can have installed capacities up to a couple of GW. The available production time depends on the size of the upper reservoir. The lifetime of the plants is between 40 to 80 years, although the electromechanical equipment has often to be replaced during this time. For a given installed capacity (which depends on the head and flow, see Equation (4-1)), the response time gets quicker with increasing head between both reservoirs (or between the reservoir and the power station in the case of storage plants). The lower the head, the more flow needs to be released through the turbine in order to reach a given

[201] The exact definitions used in Switzerland in French and German for storage and pumped-storage hydropower are given in Appendix G.

output. Therefore, high head storage and pumped-storage schemes are more adapted to react quickly for a given capacity of power demands in the grid. Thus mountainous areas are desirable, such as the Alps in Switzerland.

Swiss storage and pumped-storage plants mainly provide peak electricity production and ancillary services[202]. Their importance is not restricted to Switzerland, but to Europe as well (i.e., electricity hub – see Section 2.2). In Switzerland, they contribute towards balancing out the seasonal, weekly and daily demand changes. During the day, there are two peaks: one briefly before midday and the other around 6pm (Filippini, Banfi et al., 2001) (see also Figure 2-10). The midday peak is usually higher although during winter both peaks reach similar figures. Weekly changes are due to lower electricity consumption over the weekends. The seasonal changes vary with the climatic conditions, and more electricity is consumed during the winter. Switzerland imports electricity during winter and exports it during the summer. This export is mainly due to melting snow and the production from storage and run-of-the-river plants. However, the import-export situation is more complex than the reverse of seasonal flow. The Swiss pumped-storage plants pump water during the night with imported electricity and export the production during peak time. The overall annual import-export electric energy flows are balanced (BFE, 2011d), in contrast to the financial flows which are significantly in favour of the Swiss plants. In the future, the Swiss storage and pumped-storage plants could have an increasing importance in enabling the large scale integration of intermittent RETs within Europe.

In Switzerland, storage plants account for 60.1% of the total hydropower installed capacity and pumped-storage for 13.8%. Table 7-1 shows the current installed capacities. In comparison and for pumped-storage plants, there are 132 GW installed worldwide (Uniyal, 2010). This accounts for about 500 plants with an average installed capacity of 300 MW, whereby new plants are more likely to have installed capacities between 1-2 GW (Lempérière, 2011). Beside pumped-storage plants in mountainous areas, such plants could be further developed onshore with sea water, as well as in flat areas with new schemes (Lempérière, 2011).

Table 7-1: Storage and pumped-storage plants in Switzerland in 2010

Installed capacity at generator [MW]	Storage plants		Pumped-storage plants	
	Number	Capacity [MW]	Number	Capacity [MW]
< 1	1	0.4	0	0
< 10	18	105.8	3	14.7
> 10	67	8'157.2	14	1'878.8
Total	86	8'263.4	17	1'893.5

Source: (BFE, 2011g)

Table 7-1 shows the minor role of S&P/S-SHP plants compared to large hydropower today. Only 22.3% of the storage plants and 17.6% of the pumped-storage plants are below 10 MW (see Appendix H for a list of all plants). Compared to SHP in general, which is about 89.1% of the number of hydropower plants (above 300 kW), these figures for S&P/S-SHP are very low. The potential of S&P/S-SHP in Switzerland has not yet been fully evaluated. The different options of S&P/S-SHP are developed in Section 7.3 aiming at optimising the use of existing and planned infrastructures. S&P/S-SHP can contribute towards dealing with the daily and in certain cases where the reservoirs have important capacities, with the weekly fluctuations in the electricity sector. S&P/S-SHP could therefore partly substitute the daily grid balancing of large storage and pumped-storage plants which could keep their capacity to use during the winter.

[202] See Section 8.2.1 concerning ancillary services.

In the seventies and during the development of nuclear power plants, about thirty pumped-storage schemes were evaluated in detail in Switzerland (BWW, 1972). They were all near planned nuclear power plant sites in order to store superfluous electricity generated during the night. With the giving up of additional nuclear power plants and with the favourable conditions for peak electricity from storage plants, the interest for pumped-storage schemes was significantly reduced (Schleiss, 2007). It is only with today's development of intermittent RETs that the interest is back (see next Section).

Currently, several large pumped-storage schemes are under construction or planned in the near future. Under construction are Nant de Drance[203], a 900 MW project, and Linthal 2015[204], a 1'000 MW project. Furthermore, the project Lago Bianco (Val Poschiavo) with 1'000 MW is planned[205] and additional projects are developed at the Grimsel plants (Grimsel 3) and three other sites. In total, about 4 GW new pumped-storage capacities are planned until 2020.

In order to increase energy storage capacity, not only are new pumped-storage schemes an option, but also transforming existing storage plants into pumped-storage ones. This becomes especially interesting in the case of melting glaciers which are upstream of existing storage plants. The disappearing glacier can be replaced with a new dammed reservoir which operates as a new upper reservoir in the pumped-storage scheme.

A further option towards increasing storage with hydropower is the heightening of existing dams. According to Schleiss twelve existing dams could be heightened adding 30% to today's storage capacity[206]. This would contribute towards producing about 10-15% more electricity during the winter when Switzerland currently imports electricity.

Storage hydropower offers the opportunity to combine hydropower production with the regulation of the flow downstream of the storage capacity. Climate change is going to increasingly reduce water flows during the summer (see Section 4.2.2). Storage plants could therefore contribute towards storing water, e.g. from heavy rains and melting snow, in order to release more water during natural low flow periods (Pfammatter, Zysset et al., 2007). Furthermore, storage hydropower could contribute to flood mitigation as extreme weather events are forecasted to increase.

Storage and pumped-storage hydropower is site specific. Particular attention has to be given to the environmental integration, especially concerning the reservoirs. Social acceptance often remains a concern. However, as the Linthal 2015 project demonstrated, local and environmental opposition leading to court cases can be avoided by large stakeholder's involvement in the very early stage of the project.

With the construction of large storage or pumped-storage plants grid reinforcements often become necessary. In the case of SHP, grid reinforcements are in most cases not required[207]. However, if they are necessary, the reinforcement costs, after having been accepted by the regulator, have been paid by the TSO (Swissgrid) until 2011[208]. Swissgrid transfers these costs onto the final customers by the way of the transmission fees.

The electromechanical equipment for storage and pumped-storage schemes evolved during the 20th century. For pumped-storage plants, two types of equipment are used today: ternary groups with a turbine, pump and electric

[203] http://www.nant-de-drance.ch/home.htm (accessed on 08.08.2011)
[204] http://www.axpo.ch/axpo/en/hydroenergie/wissen/kraftwerksprojekte/ausbauprojekte_linth-limmern.html (accessed on 08.08.2011)
[205] http://www.repower.com/en/ch/anlagen/projekte/lago-bianco/ (accessed on 08.08.2011)
[206] La Liberté. Sieber, P.-A. (2011) "Des barrages toujours plus hauts, c'est l'avenir", 18.05.2011
[207] In February 2011, the ElCom had treated 5 cases of grid reinforcement linked to FIR projects (Newsletter 2/2011, www.elcom.admin.ch). At that time, about 1'600 RET plants were operating (Report Warteliste, 01.03.2011, www.swissgrid.ch). Therefore, in 3‰ of the cases, grid reinforcement was necessary.
[208] Elcom Newsletter 2/2011: http://www.elcom.admin.ch/dokumentation/00115/00117/index.html?lang=de&download=NHzLpZeg7t,lnp6I0NTU042l2Z6ln1acy4Zn4Z2qZpnO2Yuq2Z6gpJCDdIB7e2ym162epYbg2c_JjKbNoKSn6A--

motor-generator on the same shaft; or reversible groups with a reversible pump-turbine coupled with a motor-generator. The former is usually more costly, but allows optimisation of the operating range for both the turbine and pump, whereas with the latter, the turbine cannot contribute towards providing the starting torque for the pump (Avellan, 2012). With the penetration of intermittent electricity production, the changes of the mode of operation of pumped-storage plants are much more frequent. Where historically the pumping and turbining mode would change once during the day and also seasonally, today, several changes are possible within the same day. The equipment, therefore, needs to be designed to resist frequent changes of mode of operation and to operate with flexibility. Current research with variable-speed turbines and pump-turbines aims at optimising the operational flexibility (Pannatier, Nicolet et al., 2008). The operation range for turbines can today reach between 50-100% of their installed capacity and for pumps 70-100% (Teller, Kunz et al., 2011). This flexibility allows less stop&go of the electromechanical equipment and thus increases its lifetime.

Concerning the electromechanical equipment for pumped-storage SHP plants, there is at the moment no combined pump-turbine. Therefore, currently the best solution is to separately install a turbine and a pump[209]. There are opportunities to develop variable speed pump-turbines with the systematisation method presented in Section 4.1.6, to improve reversible pumps to operate in turbine mode, and to improve turbine for the pumping mode. In the case of MHP, inverse pumps can be improved to operate as variable speed turbines (Chapallaz, 2007). Should the ICT development lead to almost fully automatic smart grids which can include micro storage technologies, then pumped-storage plants of 30-50 kW could be developed. In this case, the development and production of the electromechanical equipment would be standardised.

A problem with storage reservoirs is sedimentation. Over time, reservoirs fill up with sediments thus reducing the water storage capacity. In 2006, 35% of the worldwide storage capacity had been lost and by 2050 the predicted proportion of current worldwide capacity that would be filled with sediment rises to 70% (Basson, 2010). It is expected that hydropower dams will be severely impacted when the sedimentation level reaches 80%. Many on-going research projects deal with this problem (e.g. (De Cesare, Schleiss et al., 2011)).

A final issue to mention concerning storage and pumped-storage plants is hydropeaking. Hydropeaking was introduced in Section 5.2.2 and is the subject of current research (e.g., refuge for fishes). The effects of hydropeaking are reduced mainly by constructive measures in Switzerland. With daily cycles with peak production, S&P/S-SHP plants have to include such measures.

7.2 The arguments to develop storage and pumped-storage SHP

The institutional changes, such as the liberalisation process and the national and municipal RET targets, lead in a co-evolutionary process to technological changes, such as the increase of distributed and intermittent RET electricity production (see Section 2.3.1). This increase leads to the need for more storage capacities in the electricity sector to operate the network (Denholm, Ela et al., 2010), e.g., for load shifting and smoothing. Storage capacities will develop at the large scale level (e.g., large pumped-storage hydropower plants) in order to integrate intermittent RETs and balance the grid at the national and continental level. At the regional and local level, small scale storage capacities will develop[210]. Such capacities, along with flexible production technologies, are complementary to the ICT developments (within so-called “smart grids”), which also contribute to the operation of the grid and integration of RETs at the local and regional level (see Section 3.2.3).

[209] Personal communication with Vincent Denis, Mhylab, and Prof. Cécile Münch-Alligne, HES-SO, 2011.
[210] This is in line with the Action Plan of the Federal Energy Strategy 2050 (Presentation of Pascal Previdoli, SFOE, Stromkongress, Bern, Switzerland, 17.01.2012).

A reason to develop energy storage capacities at the local and distributed level is linked to the fact that the deployment of intermittent RETs depends on the available control energy[211] within both the capacity and the system management[212]. Both managements are currently centralised. In order to decrease costs for future control energy and investment costs in telecommunication infrastructures, required to centrally operate the grid in real-time, some of the capacity and system management could be done by the distribution system operators (DSO) with distributed energy storage and flexible production capacities[213]. In addition, it would reduce energy losses, reduce network congestion and allow an operation of the grid in island mode if the distribution grid was disconnected from the transmission grid due to a problem caused, for example, by intermittent RETs. Furthermore, a multitude of small scale distributed generation units enhance reliability of the electricity network, as the probability of losing big amounts of production at a time is much reduced, and the N-1 criterion[214] is easier to fulfil. S&P/S-SHP could provide such distributed energy storage and flexible production capacities.

Figure 7-3 summarises the arguments to develop storage and pumped-storage SHP.

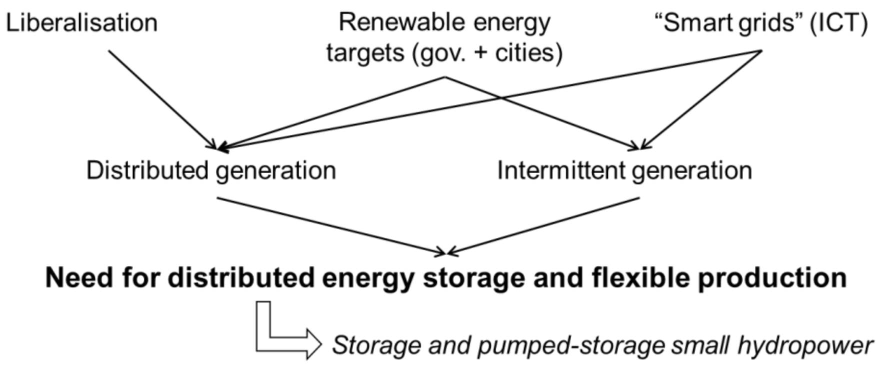


Figure 7-3: Argument to develop storage and pumped-storage SHP

The institutional facilitation of RETs currently focuses on increasing the produced electric energy quantity (i.e., kWh). However, in order to include the above consideration on additional storage capacities and flexible production due to the facilitated intermittent RETs, the institutional facilitation (i.e., mainly governmental policies) must include aspects such as the alignment between production and the actual electricity demand, available peak power and contribution to the capacity and system management of the electricity grid. For example, market-based instruments related to the electricity market which recognise the value of the storage capacities could be put in place (BFE, 2011c: XVI), as well as incentives for demand-oriented production (i.e., flexible production)[215]. It is only coherent with the RET and GHG emission reduction targets to develop additional energy storage and flexible production technologies which are renewable and have very low GHG emissions per stored energy unit. Storage and pumped-storage hydropower fulfil these criteria. They have been used for many years and are well established in the electricity market compared to the other technologies. SHP is currently the only facilitated RET which can provide flexible production, and contribute to local grid balancing and energy storage. Thanks to the

[211] Control energy, also called operating reserve, contributes to the ancillary services required for the system management of the electricity grid (see Section 2.2.1). For more information: http://de.wikipedia.org/wiki/Regelleistung_%28Energie%29 (accessed on 09.12.2011).
[212] One example is the FIR scheme in Switzerland which will lead to the need for an additional 600 MW for control energy (BFE, 2010a).
[213] Personal communication with Prof. M. Paolone, EPFL, 11.11.2011; and (BFE, 2010a).
[214] The N-1 criterion expresses the ability of the system to lose a linkage (i.e. a power line) or a node (i.e. production unit) without causing an overload failure elsewhere in the system. However, some literature questions in the meantime the application of this criterion as whether it is still adequate for the complex systems of network industries (IRGC, 2006).
[215] Presentation of Pascal Previdoli, SFOE, Stromkongress, Bern, Switzerland, 17.01.2012.

increasing quality of weather forecasts[216], the regional and local coordination between intermittent RETs and S&P/S-SHP to deal with the production fluctuations can be further improved. The argument developed in this Section is not that S&P/S-SHP is the only storage technology which should be institutionally facilitated within RETs policies, but that flexible production and energy storage needs to be included when defining the institutional facilitation of RETs.

The Energy Strategy 2050 of the Federal government recommends the establishment of an action plan including the development of energy storage technologies for electricity which could then benefit from Federal grants for demonstration plants. This is an opportunity for innovative S&P/S-SHP schemes.

S&P/S-SHP schemes are an example of co-evolution between institutions and technologies (see Section 3.2) as illustrated in Figure 7-4. The technological evolution requires further shaping of the institutions in order to implemented new storage and flexible production technologies within the overall institutional framework regarding RETs.

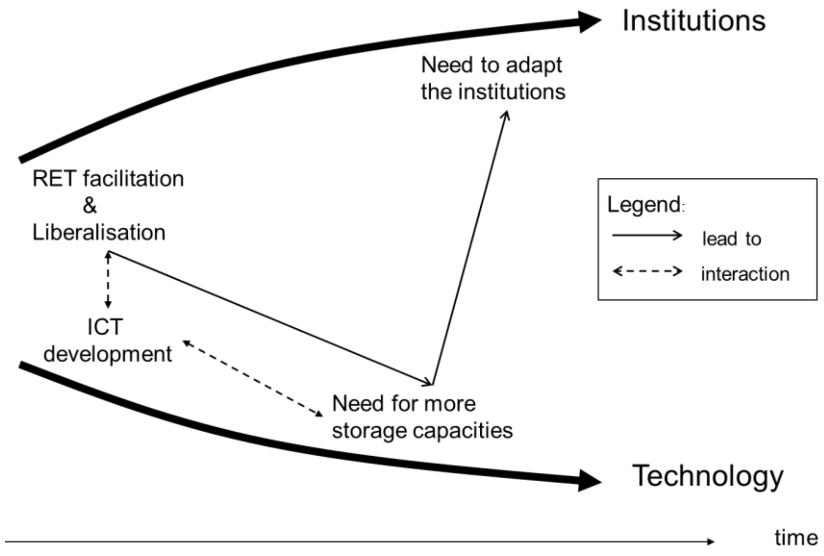


Figure 7-4: Co-evolutionary perspective of the need for more storage facilities and the evolution of the institutions

The argument to include energy storage and flexible production within the RET facilitation can be further enforced using the coherence framework and its four coherence perspectives (see Section 3.3.1). The scope of control aims at an overlapping of the technical and institutional scope. If institutions become more and more decentralised because of liberalisation and smart grid regulation, the technical way the electricity grid operates will need to become more decentralised, and will require capacities to ensure decentralised system management (see Section 3.3.1). This will require distributed storage capacities and distributed flexible production which is also supported by the coordination perspective (i.e. decentralised coordination mechanism). The territorial resolution perspective further enforces the need to ensure that at each institutionally relevant level, the system relevant functions (mainly the system management) are technically secured. Finally, the time perspective can be used as an argument that the reaction to a perturbation, for example from distributed intermittent RETs, has to occur locally as close as possible and within the same scale of capacity. Hence, it is in favour of distributed and small scale flexible production for small scale deployment of intermittent RETs. Therefore, storage RETs such as S&P/S-SHP have to be institutionally facilitated.

[216] E.g., http://www.meteocentrale.ch/en/current-weather-switzerland.html (accessed 10.08.2011)

7.3 Assessment methodology to evaluate the potential of storage and pumped-storage SHP

Before taking measures to facilitate S&P/S-SHP, its technical potential has to be systematically assessed. To this end, an assessment methodology was developed which is described hereafter. The methodology also includes some economic aspects. It considers storage SHP schemes, and, when two reservoirs are available, pumped-storage SHP schemes. The methodology was applied to the Canton of Valais[217] (see Section 1.5) and is explorative and empirical. It is illustrated in Figure 7-5. The technical potential is evaluated by looking primarily at existing and planned reservoirs (on streams and within infrastructure) as they are the relevant component for storage schemes. Furthermore, by doing so, additional civil works and thus potential negative impacts on the environment are avoided. Therefore, environmental opposition towards S&P/S-SHP projects can be reduced. In addition, costs can be saved as the expensive parts of a SHP plant are linked to civil works (see Section 4.1.3). Finally, the use of existing plants and infrastructures is in line with the latest Federal recommendations (BAFU, BFE et al., 2011). Infrastructures especially offer opportunities as multipurpose schemes (see Section 4.1.5) thus adding value to them.

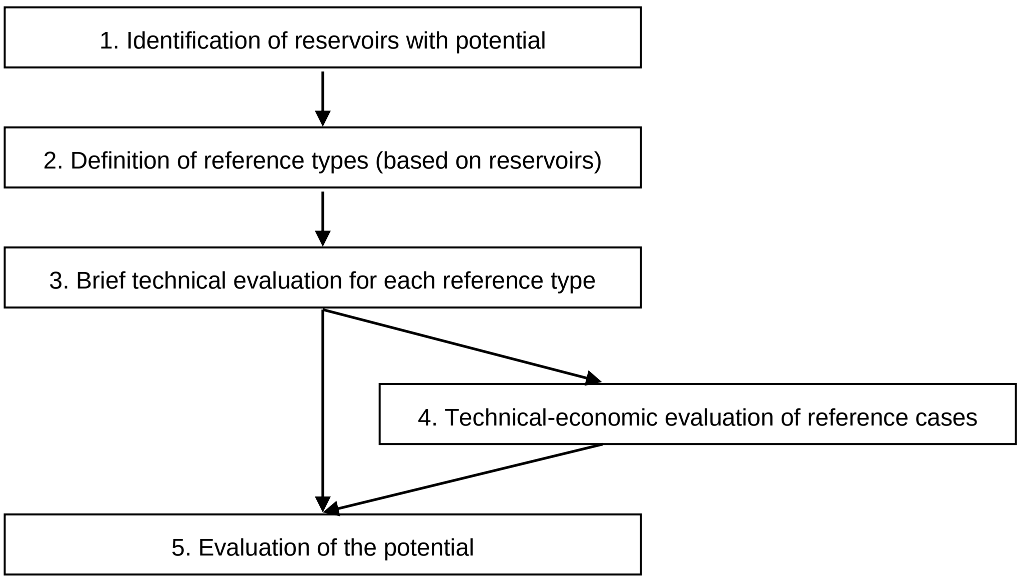


Figure 7-5: Assessment methodology for the technical evaluation of the S&P/S-SHP potential

7.3.1 Identification of reservoirs with potential

Firstly, a list of potential reservoirs was established (see Table 7-2). The reservoirs evaluated have a capacity that should at least allow a daily production of three hours with an installed capacity corresponding no less than the lower limit of 300 kW. The lower limit was chosen for data access reasons (the yearly Federal hydropower statistics only considers plants above 300 kW). The three hours account for the peak demand (see Section 7.1.2) or a minimum capacity for grid services[218]. Depending on the head, therefore, the minimal volume of a reservoir can be obtained depending on the inflows (e.g., for a storage plant with 100 m head, the reservoir has to be about 4'000 m^3 and the inflows must fill it daily). The volume is reversely proportional to the head. In order to be able to use small reservoirs, high heads are required.

[217] The Cantonal government wants to specifically increase storage hydropower and concentrate on developing its pumped-storage potential (Cina, Balet et al., 2011).
[218] If the electricity pricing and operating change with smart grid development in such a way, that short pumped-storage cycle become economically viable, then multiple pumped-storage cycle are possible per day.

When developing S&P/-SHP plants with reservoirs from infrastructures (e.g., artificial snow making, irrigation, and drinking water), the hydropower usage has to be integrated into the initial usage of the infrastructure. For example, artificial snow making reservoirs must always have enough water in order to produce the required snow.

Table 7-2: Reservoirs for S&P/S-SHP plants

Options for reservoirs	
Stream	Dammed stream (e.g., SHP plant, flood protection weir)
	Natural small unused lake
	Glacier (with global warming glaciers become new lakes)[1]
Underground water	Underground water lake
Infrastructure	Artificial snow making reservoir
	Irrigation reservoir
	Drinking water reservoir
	Waste water reservoir
	Unused military infrastructure
	Inoperative gallery
	Unused mining gallery

[1] By 2050, 75% of the alpine glacier surface with its water storage could be lost (Pfammatter, Zysset et al., 2007). Global warming will change the infiltration rate as well as the soil structure becomes more permeable.

7.3.2 Definition of reference types

Based on the most promising reservoir options according to the qualitative research (i.e., interviews and participatory research), some reference types have been defined as shown in Table 7-3. The name of each reference type was chosen according to the reservoir with the largest capacity within the evaluated scheme.

The evaluation with reference types and cases was chosen because they were no existing and accessible databases regarding all these different types of reservoirs. The required data (i.e., volume, coordinates and altitude of reservoirs, hydrology, and pipe characteristics) could not be obtained in a systematic way and had to be gathered by identifying single reservoirs and projects. However, in the case of the Canton of Valais, all Communes had already been contacted concerning the potential of SHP a few years ago (Blueark program, see below) and some data could be used. The Communes are key stakeholders in gathering information especially on the reservoirs within infrastructures. Table 7-3 shows the different sources per reference type that can be used (Appendix I shows the exact sources in the case of the Canton of Valais).

Table 7-3: Reference types and their evaluation sources for Switzerland

Reference type name	Description	Sources for the potential evaluation
SHP plant	New or additional storage capacity can be built at a SHP plant, or the existing storage capacity can be used to adjust its production. *Comment: As the administrative procedures are already heavy (see Section 6.1) and environmental opposition likely, the storage capacity should be added on existing or planned SHP plants and not on totally new schemes.*	- SHP plants databases - Database of SHP plants receiving institutional facilitation (e.g. FIR) - Contacting the electricity producers - Reports on storage plants
Lake	Existing or future lake (former glacier) where the environmental value allows the use for hydropower production.	- Database of lakes from the authorities - Google-earth and maps
Flood protection infrastructure	Hydropower usage combined with rehabilitation or new flood protection infrastructure. *Comments: Due to climate change, more extreme events can be expected which require additional flood protection infrastructures.* *Storage capacity must be emptied before a flood. Storage capacity has to be protected from sediments and rocks or emptied after floods.*	- Database of flood protection infrastructure from the authorities - Reports on weirs
Artificial snow making infrastructure	Artificial snow making reservoir which can be used in summer for hydropower usage. Positive effect for artificial snow making in winter thanks to pumping option in case of pumped-storage schemes. *Comment: Due to global warming, more of these infrastructures will be necessary for economic reasons (tourism).*	- Database of storage facilities for artificial snow making reservoirs from the authorities - Contacting the main ski resorts
Irrigation infrastructure	Irrigation reservoir in mountain areas which can be used in winter and partly in summer for hydropower usage. *Comment: Due to global warming, more of these infrastructures will be necessary for the agriculture.*	- Database of irrigation reservoirs from the authorities - Contacting the Communes based on the database
Drinking water infrastructure	Drinking water reservoir in mountain areas which has been designed to cover peak demand during the tourism season and offers potential during off-tourism time.	- Database from the authorities
Unused military infrastructure	Military bunker or gallery, which is not used anymore, is to be sold and can thus be used as reservoir.	- Contacting the military department
Inoperative gallery	Gallery which has been built for the construction of a large hydropower scheme is unused today and can be used as reservoirs (while taking into account legal, safety and structural aspects). Purge gallery which is not used anymore due to the sedimentation in the reservoir and thus can be used as storage facility for hydropower usage.	- Contacting the owners of large scale hydropower plants

Comparing Table 7-3 with Table 7-2, the following reservoir options were not considered further:

- Underground water lake: The research on SHP with underground water is just starting. In addition, there was no data for the Canton of Valais. It is a topic for further research.
- Waste water infrastructure: The water quality is a problem if storage applications are evaluated.
- Unused mining gallery: There are no such infrastructures in Switzerland. In neighbour countries, former open coal mining structure could be used (Zach, Auer et al., 2012).

7.3.3 Brief technical evaluation for each reference type

A brief technical evaluation was conducted for each type, followed by identifying some reference cases. The brief technical evaluation concerns rough estimates of the installed capacity of identified schemes based on the available sources (see Table 7-3). Identified schemes, which look promising after a first contact with a local actor, and for which more data could easily be obtained with site visits and/or meetings with local actors, were chosen as reference cases. These cases were evaluated in more depth with an Excel-based tool introduced below. The reference cases contribute towards the adjustment of the brief technical evaluation of each reference type.

The brief technical evaluation in the case of the Canton of Valais is given as example in Appendix L.5.

7.3.4 Technical-economic evaluation of reference cases

An Excel-tool was developed during the research inspired by existing tools such as in Table 7-4. These tools help to design a SHP plant and evaluate its costs. They are not tools for the evaluation of the SHP potential within a given area.

Table 7-4: Used existing decision-making tools for SHP (alphabetic order)

Tool name	Description / Usage	Source / Link
Blueark	Simple Excel-based tool for shallow technical-economic evaluation of a SHP plant.	(Dubas and Pigueron, 2009)
Hydro Resource Evaluation Tool	Complete online tool for SHP plant development including technical, environmental, economic and social aspects.	Lancaster University http://www.engineering.lancs.ac.uk/lureg/nwhrm/tool/
POPEHYE	Standardisation of civil engineering works of small high-head hydropower plants tool for designing a SHP plant.	(Andaroodi and Schleiss, 2005) http://infoscience.epfl.ch/record/116175?ln=en
RETScreen Hydro	Excel-based tool for technical-economic design of a SHP plant, including sensitive analysis.	http://www.retscreen.net/
TURBEAU	Tool for the technical-economic evaluation of a SHP plant within drinking water networks.	(Boillat, Bieri et al., 2010) http://infoscience.epfl.ch/record/162258

Sources: in the table

The research tool considers an upstream reservoir and, if existing or planned, a downstream reservoir. The latter can be within a pumped-storage plant or storage plant with auxiliary pump. If an S&P/-SHP scheme of more than two reservoirs has to be evaluated, then the scheme needs to be divided into several projects each with a maximum of two reservoirs.

In case of pumped-storage plants and storage plants with auxiliary pump, the tool considers daily pumped-storage cycles as explained in Section 7.1.2.

For each reference case, additional data is gathered in order to complete the input variables of the tool. The main input and output variables are given in Table 7-5 [219]. The capacity flow and pipe diameter has to be optimised within the tool based on friction losses calculated with the Colebrook-White formula. The data are obtained by

[219] Within the Excel-sheet for the data introduction, yellow market variable are the input variables. Green market variables have to be optimised. If a control variable is violated, the variable appears in red.

field visits, contacting the owner or project promoter of the corresponding reference cases and from the sources for the brief evaluation of the reference types (see Table 7-3).

The hypotheses within the tool are given in Appendix J.

Table 7-5: Input and output variables of the evaluation tool for S&P/S-SHP plants

Input variable		**Main output variable**	
Name	**Unit**	**Name**	**Unit**
Reservoirs		**Installed capacity**	MW
Altitude	m	**Installed pump capacity**	MW
Volume	m^3	**Annual production**[4]	GWh
Inflows (simplified[1])	m^3/day	**Annual pump consumption**	GWh
Outflows (simplified[1])	m^3/day	**Pumping time**	hours
Distance to nearest road	km		
Distance between reservoirs[2]	km	**Net head**	m
Distance between power station and electricity grid	km	**Cycle efficiency** (if pumped-storage)	-
SHP plant component (water intake, dam, fish-bypass, pipe[3], electromechanical equipment, power station, etc.)	Existence / non-existence		
Optimisation variable			
Name	**Unit**		
Flow capacity	m^3/s		
Pipe diameter (if no pipe yet)	mm		

[1] Three typical days are considered: winter, snow melting, end of summer. The year is divided into three seasons according to the three typical days.

[2] In case of a pumped-storage plant, the power station is assumed to be at the downstream reservoir (altitude, distance). In case of a storage plant, the distance is given from the upstream reservoir to the power station.

[3] If the pipe exists, the diameter has to be introduced in the tool.

[4] The annual production is calculated with 3-5 hours of daily production. Minimum 3 hours as explained above.

The tool includes an economic evaluation module which gives first estimates of investment and operation and maintenance costs, as well as production costs (cts/kWh). The required financial remuneration to enable economically viable project can thus be deducted. However, this part of the tool needs to be more refined and calibrated based on feasibility studies of possible S&P/S-SHP projects as well as completed projects.

The economic module is mainly based on formulas from the tools mentioned in Table 7-4. The formulas use technical variables calculated beforehand, except for the pumping price[220] and financial subsidies. For example, the costs of the turbine are based on the installed capacity. All formulas can be found in Appendix K.

The tool includes a sensitivity analysis module. The most sensitive variables are the inflow and outflow of the reservoirs, except for pumped-storage plants where the hydrology matters much less. To obtain the hydrology data for each reference case is beyond the scope of this research. Therefore the hydrology was based on qualitative data obtained using field visits and meeting local actors. Clearly, the hydrology study has to be developed within feasibility studies of possible projects.

[220] The tool does not currently include pumping rules such as pumping when the electricity price is below a given figure, when upstream reservoir has available capacity or when the downstream reservoir overflows. This is something to consider for future development of the tool.

The sensitivity analysis, however, is conducted on the optimisation variables. The variation of the pipe diameter and flow capacity can be evaluated along the output variables.

The tool is given in the Appendix L.4.

Finally, it should be noted that this evaluation does not replace pre-feasibility and feasibility studies, which are required to further develop and evaluate projects. This evaluation helps decision-makers to assess which projects are worth being further developed. Not all reference cases can become feasible projects.

7.3.5 Evaluation of the potential

The brief technical evaluation of the reference types completed with the reference cases evaluation leads to estimates of the technical S&P/-SHP potential within the geographical unit of evaluation (e.g., Canton of Valais in this research). The results of this unit are extrapolated for the whole country (or final area of evaluation) based on four criteria and the rule of proportion:

- Geographical surface (taking into account only the mountain areas as the head is key – see above): accounts for potential on streams and lakes
- Population (taking into account only the mountain areas as the head is key – see above): accounts mainly for the potential within infrastructures
- SHP plants in operation: account for the existing use of the SHP potential
- SHP plants (in operation, planned) benefiting from institutional incentives such as feed-in tariffs or FIR in the case of Switzerland: accounts the closest to the remaining SHP potential

The sources and applied extrapolation is given in Section 8.1.3 with the analysis and results.

Conclusion

This Chapter developed the arguments in favor of S&P/S-SHP after having introduced energy storage technologies, in particular storage and pumped-storage hydropower. The institutional changes in the electricity sector lead to the need for more energy storage and flexible production capacities to cope with the increasing deployment of intermittent RETs. Technological changes such as the development of S&P/SHP are necessary within a co-evolution between institutions and technologies. Therefore, an assessment methodology to evaluate the technical potential of S&P/S-SHP was developed. The limitations of the methodologies are threefold. Firstly, only existing and planned plants and infrastructures were evaluated thus not accounting for all the remaining potential. Secondly, the electricity production evaluation remains a first rough estimate as more data would be required on the hydrology. Finally, the economic evaluation has to be calibrated with feasibility studies and the construction of real projects. The methodology is applied in the next Chapter.

8. Analysis and discussion of the development of storage and pumped-storage small hydropower in Switzerland

This Chapter evaluates and discusses the technical potential of storage and pumped-storage small hydropower (S&P/S-SHP) in Switzerland and analyses the further shaping of the institutional framework in order to develop this potential. Based on the designed assessment methodology of Section 7.3, the technical potential of storage and pumped-storage small hydropower is evaluated in Section 8.1 firstly for the Canton of Valais and then for Switzerland. The development of the potential depends upon the evolution of the institutional framework such as the implementation of adequate remuneration instruments. This is discussed in Section 8.2, which is completed by some further institutional considerations.

8.1 Evaluation of the technical potential of storage and pumped-storage SHP

During the qualitative research (i.e., interviews, survey) the potential of S&P/S-SHP was discussed which lead to a qualitative evaluation and to the conclusion that it was worth evaluating the potential quantitatively in a next step. The qualitative results are firstly discussed before the quantitative evaluation is presented.

8.1.1 Qualitative evaluation of the potential

During the interviews, one question asked was if there is currently a technical potential for S&P/S-SHP[221]. Table 8-1 summarises the answers and some more detail follow below.

Table 8-1: Qualitative evaluation of the S&P/S-SHP potential through the 19 interviews

Interview answers to the following question: ***Is there a technical potential for storage and pumped-storage SHP?***	**Number of answers**
Yes	9
Yes, but only within infrastructures	4
Yes, but only for storage SHP	1
No	0
No opinion	5

Remark: see Table 1-2 for the list of the interviewees.

The interviewees with no opinion were in favour to study the idea further. The interviewees seeing a potential only within infrastructures underlined the oppositions and environmental challenges for projects on streams. The favourable answers without restrictions came mainly from actors involved in the design, construction and operation of SHP plants. They know well the situation in which S&P/S-SHP has potential, although they might be biased and have a too favourable opinion. Overall, the interviews showed that there is a technical potential for S&P/S-SHP, or that it should be studied further. Therefore, the quantitative evolution followed. The interviews

[221] Question 3.a in CH-interviews and Question 1.a in VS-interviews.

contributed towards elaborating the reference types of the quantitative evaluation methodology (see Section 7.3) and towards identifying some reference cases developed below.

Within the survey sent to all SHP operators receiving the FIR in 2010, the questions below were asked. The survey was sent and analysed in parallel to the interviews (see Section 1.6). The answers are given in Table 8-2.

Survey questions:

7.1 Should the production of peak electricity from SHP be facilitated with additional measures (e.g., premium for peak electricity)?

7.3 Should the facilitation of pumped-storage SHP be included in the facilitation of renewable energy technologies?

Table 8-2: Survey answers concerning S&P/S-SHP (N=166 responses)

Question		ALL	100-300kW	300-1'000kW	1-3MW	3-10MW	DCPP	DWPP	ROPP
Total		**166**	**22**	**25**	**10**	**5**	**32**	**76**	**52**
	Yes	62	6	12	5	1	10	27	21
7.1.	**Total**	**137**	**20**	**23**	**10**	**2**	**28**	**61**	**43**
	Percentage	45.3	30.0	52.2	50.0	50.0	35.7	44.3	48.8
	Yes	49	6	10	4	2	13	15	19
7.3	**Total**	**125**	**19**	**21**	**9**	**4**	**27**	**50**	**44**
	Percentage	39.2	31.6	47.6	44.4	50.0	48.1	30.0	43.2

Legend: DCPP: derivation power plant (power station separated from dam)

DWPP: drinking water power plant

ROPP: run-of-the-river power plant

Source: (Manser, 2011, Tab. 32)

The positive answers were below 50% overall, which was unexpected. However, the sample must be regarded from two perspectives: the installed capacity and the type of plant. Firstly, only 15 plants are above 1 MW (9%) and 40 above 0.3 MW (24%). The “yes” response rate tends to increase with increasing installed capacities. As the research of this thesis looks at installed capacities from 0.3 to 10 MW, the corresponding part of the sample is too small to derive clear conclusions. Nevertheless, there is more support for facilitating peak electricity from SHP than facilitating pumped-storage SHP based on the received answers.

Secondly, 76 plants are drinking water (46%). The drinking water power plants are mostly below 0.3 MW and thus their answers are not representative for this research. Furthermore, run-of-the-river and derivation power plants were built to produce in base load or at least with a high load factor. Most plants are thus inappropriate for storage. Therefore, the survey results have to be considered with caution.

The interviews delivered a more pertinent evaluation as key stakeholders within the research topic were involved. In addition, in the case of the survey, the questions were sometimes answered by staff not very familiar with the technology but more with the FIR accounting. Nevertheless, the survey has led to the identification of three projects in the Canton of Valais where a reference case could be developed.

Finally, participatory research (e.g., presenting S&P/S-SHP as opportunity at conferences and workshops) led to additional feedbacks on the potential of S&P/S-SHP. None of the received feedbacks was along the lines of there is no such potential. On the contrary, feedbacks such as from academia, engineer offices, the SFOE and turbine producers were in favour of studying the S&P/S-SHP potential and opportunities.

8.1.2 Evaluation of the technical potential in the Canton of Valais

The assessment methodology of Section 7.3 was applied to the Canton of Valais. In this Section each reference type is discussed and the reference cases presented, followed by the results for the Canton. Within the Canton eleven reference cases were identified. The numbering of the cases follows the chronological order in which they were studied.

The description of the reference types are given in Table 7-3 and the sources for their evaluation in Appendix I. The results are summarised in Table 8-12 and a detailed table given in Appendix L.5.

1) SHP plant

The construction of new SHP plants is challenged by environmental protection. The most promising sites are already used. Therefore, mainly existing SHP plants were evaluated. Some planned plants were identified and integrated in the evaluation if storage capacities could be added. The evaluation did not include future SHP plants which already applied for the FIR (on the waiting list or with approved FIR but not in operation yet) as no data can be publicly obtained on the location of such plants. Some additional potential may therefore have been omitted.

The existing SHP plants were not initially designed for storage and pumped-storage, with the exception of a few plants (see Appendix H – in the Canton of Valais, four storage plants account for 26.7 MW and two pumped-storage plants account for 9.65 MW). Nevertheless, some plants are suitable for storage schemes. Reference case 9 is an example.

Planned SHP plants were identified during the qualitative research. They have the possibility of adding storage capacities to their design development. Reference cases 8 and 11 are examples.

Table 8-3 illustrates the evaluation. The difference between minimum and maximum installed capacities is because some plants have a higher uncertainty on the feasibility of adding storage or pumped-storage facilities. The detailed evaluation is given in the Appendix L.6.

Table 8-3: Brief evaluation of the technical potential of the reference type "SHP plant" (installed capacities are the sum of the projects of one line)

Reference type: SHP plant	Category: Storage or pumped-storage	Number of sites	Reference case numbers	Total min. installed capacity [MW]	Total max. installed capacity [MW]
Planned SHP plant	Storage	3	8, 11	5.9	7.7
Existing SHP plant	Storage	18	9	11.4	23.3
	Pumped-storage	2	-	1.4	2.4

The reference cases are:

8. SHP project where storage could be added[222]

The current project designs 4-5 MW as installed capacity. Storage capacity could be added. Not much more information could be obtained as the project promoter wishes to keep the project confidential.

[222] Source: confidential

9. 4 SHP serial plants where storage could be added[223]

The following four plants operate today in a serial scheme: Härdbord, Breite Stäg, Unterbäch and Turtig[224]. After each plant, additional inflows are added to the previous flow. The first water intake is at the lake Grosser See on the Commune of Unterbäch. The capacity of the lake could easily be increased to 10’000 m^3. With its existing or increased storage capacity, the lake could serve as storage and the production adjusted in order to operate partially as four storage plants as a serial scheme. The additional production costs taking into account the dam to increase to lake storage capacity would be very low (see Table 8-11).

11. SHP project where storage could be added by increasing the size of an existing reservoir upstream of the water intake[225]

The Commune of Vionnaz developed a SHP project with an installed capacity of 1.9 MW and which was initially designed as a run-of-the-river plant. However, its adaptation to a storage plant was studied during a master thesis (Mailler, 2011) accompanied by the author of this thesis. Upstream of the water intake on one of the two river branches which bring water to the intake, an existing weir was built as to create a fire tank. This weir could be heightened to increase its storage capacity. Stored water could be released on demand.

The economic viability of this idea can be demonstrated even if the institutional framework does not change. The reservoir can store water which is released when the stream of the second branch has not enough flow to produce electricity at full capacity. Thus the plant can catch more of the annual available flows and produce at full capacity during more hours a year. The additional investment costs for the storage are 100’000 CHF which increases the production costs by 0.08 cts/kWh. An additional income of some hundreds CHF/year can be generated.

The SHP project intends to receive the FIR. Another remuneration instrument could be CO_2-credits. Vionnaz is very close by the Chavalon GCC plant which is likely to be built. In order to improve the local acceptance of the GCC plant, the CO_2 compensation of this plant could be linked with financing this SHP project, as well as the project of the reference case 4 which is in the same Commune.

This project could also be transformed into a pumped-storage project. A reservoir close to the planned power house would have to be increased from 800 m^3 to 2’500 m^3. An additional pipe would have to be laid between the water intake and the upper reservoirs. Keeping the same installed capacity and with two cycles a day, the plant could generate electricity during five hours a day. The required spread to reach financial viability would be around 0.13 cts/kWh (Mailler, Heller et al., 2011).

2) Lake

Inspired by the large scale project Linthal 2015 which will use the previously unused lake Muttsee within a new pumped-storage plant, similar small scale plants could be developed. However, the competition for the water resources in Valais is fierce[226]. Therefore, SHP plants with lakes are the most likely to be built if they are part of multipurpose schemes, in addition to being well integrated environmentally. Such a possibility has been identified and further developed as reference case 2.

[223] Field visit 04.08.2009, Phonecall with Augstbord Energie SA 17.03.2011.
[224] http://www.unterbaech.ch/gemeinde/energie.html (accessed 23.08.2011)
[225] Field visit 31.01.2011; Meeting with Mr. Alphonse Veuthey, Major of Vionnaz, 18.04.2011; (Mailler, Heller et al., 2011).
[226] Interview VS-8

A further option is to use existing artificial lakes for S&P/S-SHP. The reference case 7 is an example and concerns two existing artificial lakes used for hydropower where a rehabilitation project is currently in design.

Table 8-4 shows the evaluation. In addition to the reference cases, eight lakes where identified which have potential to be used for S&P/S-SHP. However, due to the number of uncertainties (e.g., environmental opposition, water use for other purposes, the hydrology, etc.), only one project was counted in the evaluation.

Future lakes created as a result of the melting of glaciers are not considered. A recent research evaluated possible projects for large hydropower in the Swiss Alps (Terrier, Jordan et al., 2011). It can be assumed that potential for S&P/S-SHP will arise as well (e.g., at today's Rhône glacier). This could be studied in future research.

Table 8-4 Brief evaluation of the technical potential of the reference type "Lake" (installed capacities are the sum of the projects of one line)

Reference type: Lake	Category: Storage or pumped-storage	Number of sites	Reference case numbers	Total min. installed capacity [MW]	Total max. installed capacity [MW]
Existing lake	Pumped-storage	2	2, 7	4.8	10.9
	Storage, ev. Pumped-storage	1	-	0.0	0.6

The reference cases are:

2. Lake to be used within a multipurpose and pumped-storage scheme[227]

   The Lac de Louvie[228] in the Val de Bagnes is already connected with the drinking water supply of Verbier, as well as with the irrigation and artificial snow making networks around Verbier. Due to the increased demand of drinking water at peak-tourist times, the local authority has requested that the artificial snow making company add storage capacities to their system (about 50'000 m^3) in order to have more available drinking water during certain periods of the year.

   Instead of adding storage capacities around Verbier, additional water could be taken from the Lac de Louvie if it had more water available. Thus the concept behind this reference case is to connect the Lac de Louvie with a downstream existing reservoir from one of the two Fionnay hydropower plants. Both plants have compensation reservoirs of important volumes (170'000 and 300'000 m^3). The Lac de Louvie (200'000 m^3) and the compensation reservoir would operate as pumped-storage scheme for hydropower production, as well as pumping additional water up to the Lac de Louvie when needed in Verbier for drinking water, artificial snow or irrigation. However, the water would need to be treated for the drinking water supply.

   This case, however, faces institutional challenges around the existing water rights. All concerned stakeholders would have to develop a common project.

7. SHP pumped-storage project with existing artificial lakes[229]

   The Fully SHP plant of 5 MW needs rehabilitation. A pipe needs to be replaced and the opportunity is to be used to reassess the whole scheme which includes two existing dammed lakes. Besides developing

[227] Meeting with Stéphane Storelli, SI Bagnes, 24.01.2011.
[228] http://en.wikipedia.org/wiki/Lac_de_Louvie (accessed on 23.08.2011).
[229] (Berthod and Droz, 2005); Meeting with Bernard Valluy, Alpiq, 22.08.2011; Phone call with Bernard Valluy, Alpiq, 04.10.2011.

a pumped-storage scheme, which currently does not exist, the existing plant could be operated as storage SHP if adequate remuneration instruments were put in place (see Section 8.2.1). It would allow flexible production with the available water which is not used within the pumped-storage scheme. Depending on the rehabilitation project, the lower or upper lake could be used.

For this reference case, only a pumped-storage SHP plant between both lakes was considered in order to use the available water resources without taking water away from the existing SHP plant. The case was designed using the existing pipe to reduce costs. Thus the installed capacity of about 750 kW corresponds with the capacity of the currently installed pump.

However, the existing pipe could be replaced in order to increase the installed capacity by several MW. Such a design needs to be studied further in regard to the hydropeaking in the lower lake which is limited by a regulation in place.

Finally, it should be highlighted that without changes in the institutional framework in favour of S&P/S-SHP the current rehabilitation project foresees abandoning the use of the upper lake and only producing in run-off mode with the lower lake. It would thus become a simple run-off SHP plant in order to receive the FIR, but lose the usage of its storage characteristics and be a waste of existing infrastructure. This reference case is a clear example that the institutional framework must continue to evolve.

3) Flood protection infrastructure

The hydrology is going to change in mountainous regions such as the Canton of Valais due to climate change (see Section 4.2.2). Larger and more frequent flooding is likely to occur in the future and therefore flood protection infrastructures such as weirs and dams will need to be rehabilitated, elevated and/or strengthened as well as new infrastructures built.

Rehabilitation and the building of new infrastructures offers the possibility of combining the flood protection infrastructure with storage SHP, or even pumped-storage in the case of two closed-by storage capacities.

There is no database in the Canton which lists planned flood protection infrastructure projects. For this brief potential evaluation only existing dams have been considered. The Canton has a database of all dams of a certain size (see Figure 5-6) for which the Canton or the Federal State are in charge of their surveillance. Based on this database, only one flood protection dam was identified which could be combined with S&P/S-SHP (reference case 10). Small weirs which are not included in the database are very likely not to offer any potential for S&P/S-SHP due to their low head and small storage capacity. In addition and because they are not part of the Cantonal database, the data acquisition would have been too laborious compared to the results which could be expected. They were therefore not considered.

Flood protection infrastructures are filled quickly with sediments and rocks (e.g., as in the reference case 10). If S&P/S-SHP is added to such an infrastructure, a system must be put in place in order to safeguard the storage capacity necessary for the production of hydropower energy. In addition, the SHP plant has to be protected from the floods and its operation aligned to flood forecasts.

Table 8-5: Brief evaluation of the technical potential of the reference type "Flood protection infrastructure" (installed capacities are the sum of the projects of one line)

Reference type: Flood protection infrastructure	Category: Storage or pumped-storage	Number of sites	Reference case numbers	Total min. installed capacity [MW]	Total max. installed capacity [MW]
Existing weir	Storage, ev. Pumped-storage	1	10	0.3	0.5

The reference case is:

10. Flood protection dam where a storage SHP project could be developed[230]

In the Commune of Mex, several flood protection dams were constructed in the 1980's on the Torrent de St-Barthélemy (Berthod and Droz, 2005). Some of these dams have important storage volumes (e.g., max. 500'000 m3) with heights of more than 40 m although their volumes are today completely filled with sediments and rocks.

Upstream of the dam St-Barthélemy B (45 m height and 150'000 m^3 storage volume) there are three additional small dams. A storage SHP plant could be designed using the four available heads. At the first dam, a reservoir would have to be created, able to capture daily inflows in order to produce only on demand (e.g., peak electricity). Needless to say that the residual flow regulation would need to be respected.

There is available access by the existing forest path.

The current economic evaluation shows high investment costs for low production. Therefore, it seems more adequate to install a normal run-off SHP plant at a smaller installed capacity than 300 kW.

In any design for this reference case, an important detritus tank would have to be constructed and the plant protected from floods.

4) Artificial snow making infrastructure

In the Canton of Valais, several new artificial snow making infrastructures are planned in order to cope with climate change and ensure enough snow for winter activities. However, artificial snow making competes with the use of water for drinking water supply, irrigation and hydropower production. Artificial snow making infrastructures are designed to cover the demand for artificial snow during winter. Before the water is used to make snow, it can however be used in closed loops to produce electricity within pumped-storage schemes. Therefore and in order not to tap additional water resources, only pumped-storage schemes were identified within artificial snow making infrastructures.

The Cantonal database of dams under its surveillance listed two artificial snow making reservoirs which could be used for SHP pumped-storage. Both owners were contacted. Furthermore, four other main ski resorts were contacted in order to cover the main resorts in the Canton. The potential in Table 8-6 has been identified. It does not include the project "reference case 2" which is a multipurpose scheme involving artificial snow making infrastructure as well, but where the reference reservoir is an existing lake.

Most of the shareholders of the companies operating the ski lifts and artificial snow making infrastructures are the Communes. Therefore, if pumped-storage SHP schemes within artificial snow making infrastructures are to be

[230] (Berthod and Droz, 2005); Phonecall with the communal administration 18.03.2011; Field visit 04.08.2011.

developed, the lead would be at the Communal level. In certain examples, such pumped-storage plants could contribute to the local power balancing of the Commune.

Table 8-6: Brief evaluation of the technical potential of the reference type "Artificial snow making infrastructure" (installed capacities are the sum of the projects of one line)

Reference type: Artificial snow making infrastructure	Category: Storage or pumped-storage	Number of sites	Reference case numbers	Total min. installed capacity [MW]	Total max. installed capacity [MW]
1 existing and 1 new reservoir	Pumped-storage	2	1, 4	1.3	3.9
2 existing reservoirs	Pumped-storage	1	-	0.6	0.7

The reference cases are:

1. Artificial snow making infrastructure where pumped-storage could be developed[231]

   Within the ski resort of Crans-Montana a new artificial snow making reservoir is planned. It will be connected to an already complex pipe system which links the Lac de Tseuzier, a dammed lake with 50 million m^3 mainly for hydropower production, with water catchments in neighbouring valleys eastwards. The pipe system is also connected to two lakes which serve as reservoirs for the irrigation. Within the current system and the newly planned reservoir there is potential for pumped-storage SHP.

   A SHP plant is going to be built in 2012 connected to one of the lakes for the irrigation[232]. The installed capacity has been designed at 1.7 MW. It does not operate as a storage scheme. Other projects are in development although with no consideration for storage and pumped-storage SHP schemes.

   The planned reservoir and a reservoir in Montana were considered for evaluation within this thesis. As a pumped-storage scheme, the SHP plant would not use additional water resources, but only that which is already present in the reservoirs. More projects could be developed to optimise the use of all existing reservoirs and pipes.

   It should be highlighted that water resources are becoming scare in the Crans-Montana / Sierre region. An on-going research project is dealing with the water management, including hydropower [233].

   From an institutional perspective, this reference case is very complex as it involves six Communes. More development depends on the lead of the company in charge of the ski resort and the Communes concerned.

4. Planned artificial snow making reservoir where pumped-storage could be developed[234]

   The operator of the ski resort Télétorgon intends to build a new artificial snow making reservoir of 54'000 m^3. The water would be pumped from an existing downstream reservoir continually during the year to have the reservoir filled at the beginning of the ski season. The reservoir would therefore be filled only once a year.

   The infrastructure could be combined with a pumped-storage scheme using both reservoirs whereby the one downstream could be easily enlarged to 3'000 m^3. The installed capacity would be about 0.8 MW.

[231] (Berthod and Droz, 2005); Meeting with Clément Crettaz and Betrand Cassignol, CMA, 19.01.2011.
[232] Phone call with Yves Rey, Bureaux d'ingénieurs N. Cordonier & G. Rey SA, 20.01.2011.
[233] http://www.montanaqua.ch/ (accessed on 24.08.2011)
[234] Field visit 31.01.2011; (Mailler, Heller et al., 2011).

The upstream reservoirs is planned to be on French territory. The water would entirely come from Swiss territory. The question remains if the French authorities agree not only to use the reservoir for artificial snow making, for which they benefit as the ski resort is across the border, but for hydropower production as well. This will have to be further investigated if this project is further developed.

5) Irrigation infrastructure

There are many irrigation reservoirs in the Canton. In order to have enough volume, only the reservoirs within the Cantonal database of dams under surveillance (see Figure 5-6) were considered. Future reservoirs were not considered because of the lack of a Cantonal database for such projects. Each Commune would have had to be contacted which would have been shortly after they had been contacted within the Blueark program. The response rate would have been low and not representative[235].

Only pumped-storage SHP schemes were considered in order to use only the available water for irrigation and not additional water resources (same logic as with artificial snow making infrastructure). One reference case was developed (reference case 6). Where irrigation infrastructures have remaining water resources (e.g., reservoirs often overflowing), run-off SHP plants were often already constructed or designed following the FIR scheme introduction[236].

In the case that one of the two irrigation reservoirs is significantly smaller, the feasibility of enlarging this reservoir should be evaluated in order to increase the production hours or the installed capacity of the pumped-storage SHP plant.

In some identified sites, more than two reservoirs are available, thus a whole system of reservoirs could be optimised for pumped-storage schemes. In other sites, irrigation reservoirs could be combined with other infrastructures to form a system (e.g., reference cases 1 and 2).

Table 8-7: Brief evaluation of the technical potential of the reference type "Irrigation infrastructure" (installed capacities are the sum of the projects of one line)

Reference type: Irrigation infrastructure	Category: Storage or pumped-storage	Number of sites	Reference case numbers	Total min. installed capacity [MW]	Total max. installed capacity [MW]
2 existing reservoirs	Pumped-storage	4	6	0.9	3.4

The reference case is:

6. Two existing irrigation reservoirs where pumped-storage could be developed[237]

   The Commune of Arbaz has several irrigation reservoirs. According to the Commune authorities, the reservoirs have significant inflows and a pumped-storage scheme could be developed[238]. The installed capacity could significantly be increased from 0.3 MW up to 1 – 3 MW if the reservoirs of Arbaz were linked with the reservoir in the Commune of Grimisuat to a pumped-storage scheme. This is a project for further evaluation.

[235] Meeting with Jean-Pierre Sigrist et Medard Heynen, Blueark - Cimark, 09.09.2010.
[236] E.g. Icogne SHP project with Lac d'Icogne – see reference case 1.
[237] (Berthod and Droz, 2005); Phone call with communal administration, 15.03.2011.
[238] Phone call with M. Sylver Sermier, 15.03.2011.

6) Drinking water infrastructure

The hydropower potential of drinking water infrastructures was investigated by the Blueark program (see Section 4.2.3). Feasible projects applied for the FIR and are/will be constructed. Pumped-storage schemes were not evaluated for two reasons. Firstly, the requirement for the water quality must be safeguarded which in pumped-storage schemes would be more difficult to fulfil due to the pumping-turbining cycles. Secondly, the rules of utilisation of the infrastructure give the priority to the drinking water use and not to hydropower production. Furthermore, the volumes of the reservoirs remain mostly too small (few hundred m^3).

However, a few options can be found for S&P/S-SHP. Firstly, if the turbine is installed after the reservoir and thus produces electricity when drinking water is consumed, the electricity production is aligned to the water consumption. Peaks in the water consumption are similar to peaks in the electricity demand. Such SHP plants on the drinking water infrastructure contribute therefore to peak electricity and could be remunerated accordingly (see Section 8.2.1).

Secondly, new infrastructures are going to be built to secure drinking water supply following climate change and growing demand due to tourism. In cases, where water has to be pumped up from a lower catchment, pumped-storage schemes could be developed (see reference case 3). As there is no database of such projects and all Communes had already been contacted through the Blueark program recently, only projects identified during the interviews and workshops were evaluated.

In cases where water is piped from a Commune that has water surpluses to a Commune which currently has water shortages, storage SHP schemes could be studied. A research project looked at the interconnection possibilities for some Communes[239], but no storage SHP potential could so far be identified. Further research is required on other interconnection projects.

Finally, should the smart grid developments lead to the creation of opportunities for micro storage and pumped-storage hydropower (e.g. 50 kW), then there would be a technical potential within drinking water infrastructures as the small volumes of the reservoir could be used[240].

Table 8-8: Brief evaluation of the technical potential of the reference type "Drinking water infrastructure" (installed capacities are the sum of the projects of one line)

Reference type: Drinking water infrastructure	Category: Storage or pumped-storage	Number of sites	Reference case numbers	Total min. installed capacity [MW]	Total max. installed capacity [MW]
Planned and existing reservoir	Pumped-storage	1	3	0.6	0.6

The reference case is:

3. Drinking water project where pumped-storage could be developed[241]

   The supply of drinking water in a small village is not guaranteed anymore during the peak-tourism season in the winter. A project of pumping water from the valley up to the village is under evaluation. This pumping infrastructure could be used for pumped-storage SHP by adding the turbine equipment.

[239] http://www.crem.ch/regieau (accessed on 25.08.2011)
[240] Interview CH-10
[241] Source: confidential

In addition, during summer, water catchments upstream would bring water to the upper reservoir. The plant could be operated as storage SHP scheme.

7) Unused military infrastructure

The data were obtained at Armasuisse who manages the military infrastructures which are no longer part of the active assets of the Swiss army. Only one site with two infrastructures of suitable size was identified[242]. It was further evaluated within the reference case 5.

Unused military infrastructures transformed into water reservoirs do not have a negative impact on the environment. For SHP plants, the environmental impact would come only from installing the pipes and power station. Thus such infrastructures would be very suitable for S&P/S-SHP from an environmental perspective. Furthermore, unused bunkers and galleries could also be connected to other reservoirs to form networks with hydropower potential.

Even though the results of this reference type are very low with only one site, there are further opportunities. Firstly, many unused military infrastructures have already been sold to private entities[243]. Not all of these sold infrastructures are used today and could therefore be transformed into S&P/S-SHP plants. There is no public database on such available infrastructures.

Secondly and in the future, additional military infrastructures will be transferred to the available assets to be sold to private entities. Additional potential will arise which is currently confidential.

Table 8-9: Brief evaluation of the technical potential of the reference type "Unused military infrastructure" (installed capacities are the sum of the projects of one line)

Reference type: Unused military infrastructure	Category: Storage or pumped-storage	Number of sites	Reference case numbers	Total min. installed capacity [MW]	Total max. installed capacity [MW]
2 existing military infrastructure	Pumped-storage	1	5	<0.3	<0.3

Remark: The total installed capacity is below the minimum of 0.3 kW because the only identified site cannot reach a production of minimum 0.3 kW as explained below in the reference case 5.

The reference case is:

5. Two military infrastructures connected to develop a pumped-storage scheme[244]

   A bunker in the mountain close to an unused storage building could be connected to develop a pumped-storage scheme. However, the building would have to be reinforced and made waterproof. Furthermore, the head is too small to design a SHP plant with at least 300 kW installed capacity and producing at least 3 hours a day. Therefore, the pumped-storage scheme is abandoned.

   However, within an interconnection project for water supply between several communes, the bunker could be used as reservoir. This might lead to a pumped-storage scheme and has to be further investigated.

[242] I.e. several 1'000 m^3 in order to reach the minimum of 300 kW with the available heads.
[243] Meeting armasuisse, 08.12.2010.
[244] Personal communication with armasuisse; Field visit 04.08.2011.

8) Inoperative gallery

For the construction of the large hydropower plants in the Alps, access galleries were built. Some of them are used today as control galleries, but only at certain periods in the year. They could be used at other periods as reservoirs if no security risks are posed to the operations of the initial hydropower plant.

The use of such galleries for S&P/S-SHP schemes raises questions around the permeability of the galleries and the ownership of possible water inflows. Furthermore, the stability of the galleries wall must be safeguarded.

During this research, some galleries were identified. However, they cannot be used to build a pumped-storage SHP plant either because of too small heads or because there is no other reservoir close by. Therefore, no reference case was developed. Nevertheless, the author might have missed some further galleries which could bear some potential for pumped-storage SHP schemes.

In addition to access galleries, purge galleries could offer some potential in the future. Due to the sedimentation problem at large storage hydropower plants, their purge galleries will eventually be no longer operational. Such galleries could be then used as reservoirs. At the current state of the research, no such examples could be found[245].

Table 8-10 summarises the reference cases and gives their installed capacities and reservoir capacities. Some of these reference cases offer the opportunity for further development (i.e., pre-feasibility or feasibility study).

[245] Communication with Prof. A. Schleiss, EPFL, 18.04.2011.

Table 8-10: Reference cases (S: storage; P-S: pumped-storage)

Reference type	Reference case (with number)	Reservoir capacity [m³]	Installed capacity [MW]
SHP plant	8. S project by creating a reservoir at the designed dam	-[1]	4 – 5
	9. S project by increasing the capacity of an existing lake of which the water is used in 4 existing serial SHP plants (combination with reference type "Lake")	10'000	3.3
	11. S project by building a small dam upstream of the water intake of a planned SHP plant. Possible transformation into a P-S project (lower reservoir of 2'500 m^3).	3'000	1.9
Lake	2. P-S project with an alpine lake which could be connected to an existing dammed lake and combined with artificial snow making and drinking water infrastructures	Upper res.: 200'000 Lower res.: 170'000	4 – 8
	7. P-S project between 2 existing lakes already used for hydropower, but not connected for P-S SHP yet	Upper res.: 4'200'000 Lower res.: 35'000	0.8 – 3
Flood protection infrastructure	10. S project with existing dam	5'000	0.3
Artificial snow making infrastructure	1. P-S project with an existing and a planned reservoir; could be combined with 2 irrigation reservoirs	Upper res.: 100'000 Lower res.: 130'000	0.5 – 2.5
	4. P-S project with a large planned reservoir and an existing reservoir to be enlarged	Upper res.: 54'000 Lower res.: 3'000	0.8
Irrigation infrastructure	6. P-S project using 2 existing irrigation reservoirs	Upper res.: 21'000 Lower res.: 21'000	0.3
Drinking water infrastructure	3. P-S project to secure drinking water for tourism village and which could include hydropower production	Upper res.: 2'000 Lower res.: 650	0.6
Unused military infrastructure	5. P-S project between 1 bunker and 1 building	Upper res.: 7'200 Lower res.: 2'700	<0.3
Inoperative gallery	-		

[1] *Remark: In the reference case 8 no data could be obtained on the reservoir capacity.*

Table 8-11 summarises the detailed results of the reference cases, including the yearly production and first economic evaluation. The final installed capacities have to be further evaluated within feasibility studies. The figures on the electricity production are first approximations. As explained in Section 7.3.4, the hydrology has to be further evaluated and is the major uncertainty in the current evaluation.

The economic figures are indicative. As mentioned in Section 7.3.4, the economic module of the evaluation tool has to be further refined. Uncertainties remain, especially the costs of the reservoirs (if they have to be constructed) and the house of the power station. These costs have to be evaluated in more detail for each single project as they are very site specific and cannot be calculated exactly by formulas as it is the case currently.

Table 8-11: Results summary of the reference cases

Reference case number	1	2	3	4	5	6	7	8	9	10	11
Reference type	Snow making	Lake	Drinking water	Snow making	Unused military	Irrigation infra.	Lake	SHP plant	SHP plant	Flood protection	SHP plant
Category	P-S	P-S	P-S	P-S	P-S	P-S	P-S	S	S	S	S
Installed capacity [MW]	0.54	7.90	0.63	0.88	<0.3	0.30	0.75	4.00	3.30	0.30	1.91
Production [GWh/year]	0.93	13.69	0.85	1.52		0.40	1.30		0.84[2]	0.18	0.10[3]
Investment costs [kCHF]	950	13'998	1'106	1'310		1'629	1'682		395	2'449	100
Production costs[1] [cts/kWh]	21.71	28.34	24.22	20.81		50.28	18.12		3.53[4]	111.20	7.66[4]
Ratio Inv. / Production [Millions CHF/GWh]	1.02	1.02	1.3	0.86		4.04	1.29		0.47	13.54	1.05
Ratio Inv. / Capacity [Millions CHF/MW]	1.77	1.77	1.75	1.49		5.38	2.24		0.12	8.18	0.05
Comment	Optimise with addition-nal reservoirs	Optimise with other infra.			Could be used only for storage in inter-connection projects	Can be combined with additional irrigation reservoir	Alpiq is on this project	Private develop.	4 plants in serial scheme		

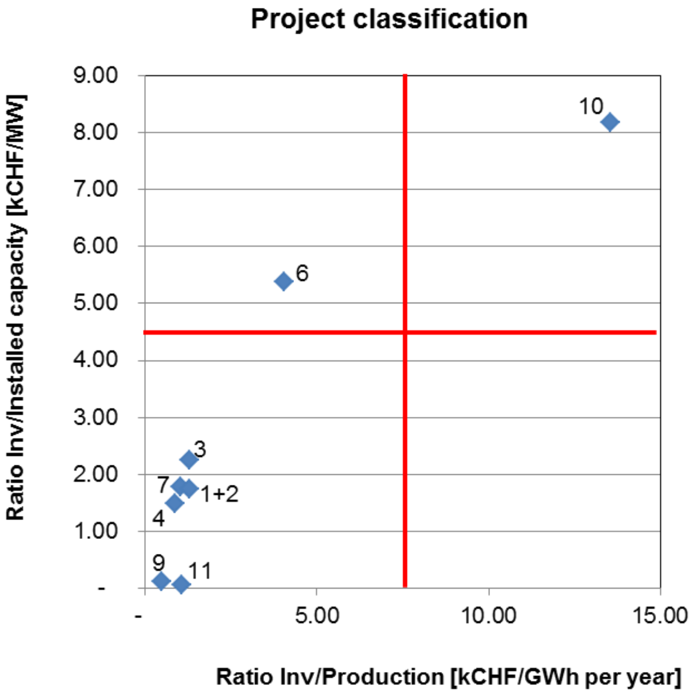
[1] *Hypothesis: For the pumping costs, 8 cts/kWh were considered. No VAT on the income in the calculation.* *Comment: S: storage, P-S: pumped-storage*

[2] *Evaluated additional production to the existing scheme. Part of today's production could be sold as flexible production and thus be remunerated with the instruments developed in Section 8.2.1.*

[3] *This is only the additional production thanks to the storage facility. The run-of-the-river plants produced 9.5 GWh a year and part of this production could be sold as flexible production and thus be remunerated with the instruments developed in Section 8.2.1.*

[4] *The production costs are so low because only the additional production costs following the new investment are considered. These costs would have to be covered by adequate remuneration instruments.*

Figure 8-1 places the different reference cases according to their ratio of investment to installed capacity and ratio of investment to annual production. Among the evaluated cases, those in the bottom left quadrant are the most promising to be further developed. The one in the top right quadrant can be abandoned and the others should be discussed before any decision is taken regarding their development.



Legend:

1: Artificial snow making – Montana

2: Lake – Bagnes

3: Drinking water infrastructure

4: Artificial snow making – Vionnaz

5: Military infrastructure

6: Irrigation – Arbaz

7: Lake – Fully

8: SHP plant

9: SHP plants – Unterbäch

10: Flood protection infrastructure – Mex

11: SHP plant – Vionnaz

Remarks: It has to be highlighted that the annual productions are first rough estimates, thus this ratio is less significant than the ratio Inv./Installed Capacity. Furthermore, the comments of Table 8-11 should also be taken into account.

Figure 8-1: Reference cases comparison

In conclusion and for the reference cases:

- The reference cases 1, 2, 3, 4, 7, 9 and 11 are the most promising cases, as well as case 8 (not present in Figure 8-1 as no costing available). Reference cases 9 and 11 are priorities for development as they only involve increasing the storage capacity with an existing and planned SHP plant.
- The reference case 10 and 5 (installed capacity below 0.3 MW) should be abandoned.
- Reference case 6 is subject for further discussion.

In summary, Table 8-12 presents the evaluation of the technical potential in the Canton of Valais per reference type.

Table 8-12: Technical potential evaluation of S&P/S-SHP in the Canton of Valais

Reference type	SHP storage potential [MW]	SHP pumped-storage potential [MW]
SHP plant	17.4 - 31.0	1.4 - 2.4
Lake	0.0 - 0.6	4.8 - 10.9
Flood protection infrastructure	0.3 - 0.5	-
Artificial snow making infrastructure	-	1.9 - 4.6
Irrigation infrastructure	-	0.9 - 3.4
Drinking water infrastructure	-	0.6
Unused military infrastructure	-	-
Inoperative gallery	-	-
TOTAL	17.7 - 32.1	9.6 - 21.9

There are two reasons to explain the large spreads of the figures in Table 8-12. Firstly, some plants which have an environmental uncertainty on whether they can be transformed to storage or pumped-storage schemes were given as minimum installed capacity zero and as maximum installed capacity their actual capacity. Secondly, some reference cases can be designed with significantly variable installed capacities. For example, in the reference case 1, the installed capacity can vary by 500%, in the reference case 2 by 200% and in the reference case 7 by 300%. In order to account for these minimum and maximum values, the figures in Table 8-12 are given with these spreads.

The evaluation with the highest uncertainty on the results is the reference type "SHP plant". Planned SHP plants could not be systematically evaluated because there is no publicly available database. Most existing SHP plants were evaluated without site visit due to the high number of sites. The reason why these uncertainties have not been reduced is because before further investigation on the technical feasibility and potential of such sites, the institutional framework has to further evolve in order to remunerate adequately the S&P/S-SHP schemes (see Section 8.2.1). Therefore, the evaluation was not developed further within this thesis. However, recommendations were developed for a quantitative evaluation of the potential based on the on-going evaluation of the SHP potential (see Section 4.2.2). Additional algorithms could be introduced in the existing tool which would allow the evaluation of the S&P/S-SHP potential for whole Switzerland.

The potential evaluation is conservative. It does not consider the potential of future SHP plants on streams, glaciers melting to future lakes, additional dams for flood protection, and additional artificial snow making, irrigation and drinking water infrastructure beyond the identified future projects. Neither does it consider available military infrastructures and galleries which will become inoperative in the next years. Furthermore, there might be pumped-storage SHP potential around existing large storage hydropower schemes. The various existing reservoirs could be linked to small scale systems. This is only an option if the existing operational schemes allow for additional use of the available water. Due to this operational complexity this potential was not investigated further in this research. Finally, the possibility of using the river Rhône as a downstream reservoir was not evaluated because of the institutional complexity around this stream. However, pumped-storage SHP projects could be developed on some river sections.

To conclude, the storage SHP potential in the Canton of Valais lies almost completely with SHP plants on streams. About 2/3 of this potential is with existing plants where the increase of the reservoir capacity could be evaluated. Some potential can be found with natural lakes. The identified potential with flood protection infrastructures can be neglected. However, with future climate mitigation, new potentials could become available.

The pumped-storage SHP potential is held in various infrastructures and lakes. The most promising infrastructures are artificial snow making and irrigation infrastructures. Little potential could be found in drinking water infrastructures. Lakes also offer clear potential. However, the environmental potential has to be further investigated.

Overall, S&P/S-SHP has a technical potential in the Canton of Valais worth further developing. Compared to the existing SHP potential used today, which is of 26.7 MW storage and 9.7 MW pumped-storage, the identified additional potential is in a similar range for storage, but more significant for pumped-storage.

8.1.3 Evaluation of the technical potential in Switzerland

The results of the Canton of Valais were extrapolated based on the criteria explained in Section 7.3.5. Some more details are given with Table 8-14 which gives the different ratios for the extrapolation.

Table 8-13: The different extrapolation criteria and their value

Criteria	Ratio (value of Switzerland / value of Canton of VS)	Source	Comment
Population	7.95	Swiss statistics[1]	Data from 2010. Only mountainous areas considered[2].
Surface	4.71	Swiss statistics[1]	Only mountainous areas considered[2].
SHP plants Number of plants Total installed capacity	 8.18 6.16	Hydropower plants statistics (BFE, 2010b)	The hydropower plants statistics from 01.01.2010 was used instead of the 01.01.2011 in order to exclude more SHP plants under the FIR scheme which are taken into account under the next criteria.
SHP plants with FIR Number of plants Total installed capacity	 5.69 4.05	Stiftung KEV, Statistics on 01.01.2011[3]	

[1] www.bfs.admin.ch (accessed on 26.08.2011)

[2] Based on the 10 "Régions biogéographiques: répartitions en 10 régions" from « Atlas de la Suisse 3.0 »[246] : Evaluation to see how much of each Canton surface is part of: Préalpes, Alpes septentrionales, Alpes centrales occidentales, Alpes centrales orientales, Alpes méridionales.

[3] http://www.stiftung-kev.ch/berichte/anmeldestatistiken.html : Anmeldestatistik pro Kanton Stand 1. Januar 2010

The different ratios vary between 4.05 and 8.18. For the criteria “SHP plants” and “SHP plants with FIR” the ratios are higher with the number of plants than with the total installed capacity in the Cantons. This is due to the fact that the average installed capacity of the plants in the Canton of Valais is higher than the average installed capacity in Switzerland. The final ratio has been chosen between 5.5 and 6 which is an average of the ratio in Table 8-13 and also close to the ratios based on the FIR projects and FIR demands (ratio of 5.77 and 6.27), which account for planned projects.

The extrapolation ratio was applied with the rule of proportion to the results for the Canton of Valais (see Table 8-12). Table 8-14 summarises the results for Switzerland. The detailed extrapolation calculation can be found in the Appendix L.7.

[246] http://www.swisstopo.admin.ch/internet/swisstopo/fr/home/current/newproducts/20101126.html (accessed on 26.08.2011)

Table 8-14: Technical potential of storage and pumped-storage SHP in Switzerland

Potential in Switzerland	In operation (2010)			Additional technical potential		
	Streams[1]	Infrastructures	TOTAL	Streams[1]	Infrastructures	TOTAL
Storage SHP	106 MW	0	**106 MW**	97 - 193	-	**97 - 193**
Pumped-storage SHP	15 MW	0	**15 MW**	34 - 80	19 - 52	**53 - 132**

[1] Reference types "SHP plant" and "Lake"

Source for "In operation (2010)": (BFE, 2011g)

The important spreads in the final values are due to two reasons. Firstly, as explained for Table 8-12, the evaluation in the Canton of Valais considers minimum and maximum values, which are significantly different. Secondly, the final extrapolation ratio with a spread contributes to increase the difference between the lower and higher value. Nevertheless, it illustrates closer to the reality the additional technical potential range of S&P/S-SHP in Switzerland.

The potential is important compared to the existing storage and pumped-storage SHP plants. It is a doubling or almost tripling in the case of storage schemes and an increase by a factor between almost four and nine times for pumped-storage schemes. This accounts for the fact that existing storage SHP plants represent only 1.3% of the installed capacity of all storage plants and the existing pumped-storage SHP plants only 0.7% of all pumped-storage plants. These figures have to be compared to SHP in general which accounts for 6.3% of all hydropower installed capacity. The S&P/S-SHP potential is even more important if installed capacities below 300 kW per project are considered.

The potential must be compared to large storage and pumped-storage hydropower. For example, should the whole pumped-storage SHP potential be constructed, it would only be about two thirds of the second biggest existing pumped-storage plant Force Motrices Hongrin-Léman (FMHL) which has currently an installed capacity of 240 MW (BFE, 2011g). Furthermore, if large pumped-storage schemes presently under construction or in development are considered (e.g., Linthal 2015, Nant de Drance, Lago Bianco) which are designed with capacities around or above 900 MW, then the debate leads to whether to build pumped-storage SHP schemes at all or of whether to add another large scale project. The argument could be similar for storage plants. Instead of building several storage SHP plants one could build one new large scale storage plant. However, small and large scale plants are not in competition, but complementary. Large scale schemes are built with an international perspective of operation (e.g., European super grid), whereas small scale schemes should be built with a regional and local perspective and are necessary for the decentralised operating of the grid. In addition, the pumped-storage SHP potential is mainly found within infrastructures and multipurpose schemes, thus adds value to such schemes without bringing major additionally negative environmental impacts. In the case of the storage SHP potential, it lies mainly with existing plants where the impact on the environment can be minimised. Therefore, S&P/S-SHP plants should be further developed and constructed.

In conclusion, the technical potential is important enough to shape the institutional framework in order to develop adequate remuneration instruments. This is analysed in the next Section. Furthermore, once the institutional framework changes, additional projects will emerge (e.g., with irrigation, artificial snow making and unused military infrastructures, galleries, etc.). This research therefore contributes to identifying the potential of S&P/S-SHP and launches the discussion on changing the institutions in a co-evolutionary process.

The limitations of this evaluation are its explorative and bottom-up approach. Some potential has been omitted. The technical evaluation was based on brief studies of the different reference types. These different reference cases would need to be further studied and the most promising ones developed into real projects in order to have a more accurate technical, as well as economic, evaluation of the potential. To remedy these limitations further research options have already been mentioned such as the more top-down quantitative evaluation of the S&P/S-SHP potential on streams or the evaluation of melting glaciers as future lakes.

8.2 How to shape the institutional framework to develop the storage and pumped-storage SHP potential

The institutional barriers for S&P/S-SHP are economic and environmental. Within economics, the main barriers are the higher production costs compared to other technologies which can store energy and/or produce on demand (e.g., large storage and pumped-storage hydropower, GCC). As developed in Chapter 5, technologies which are not yet cost-competitive in the liberalised electricity market require economic facilitation in order to be developed (e.g., SHP). Following the argument for energy storage and flexible production within RET facilitation (see Chapter 7), S&P/S-SHP has to be economically facilitated with adequate remuneration instruments. Some instruments were identified and are developed below. This argument, however, can be disputed. Indeed, it can be argued that institutional facilitation should focus solely on producing quantity of electricity from RETs. The ancillary and spot markets have to ensure the alignment between demand and supply, including peak and flexible production, which would be more economic when provided for example by large storage hydropower[247]. In the long term, markets might ensure the alignment between demand and supply from all RETs. However, this research argues that as long as RETs are institutionally facilitated, the associated technical consequences linked to this facilitation have to be considered (e.g., intermittent production). Therefore, energy storage and flexible generation has to be included in the RETs facilitation.

On the environmental side, in addition to the environmental considerations for SHP in general, hydropeaking has to be especially taken into account. Hydropeaking and its regulation were described in Section 5.2.2. As the law has recently been reviewed, hydropeaking regulation will not change again in the coming years and was not further studied. Another environmental concern related to S&P/S-SHP is the residual flow regulation which is investigated below in Section 8.2.2.

The administrative procedures for S&P/S-SHP are the same as for SHP in general (see Section 5.2). The same suggestions concerning the simplification, streamlining and harmonisation account for S&P/S-SHP (see Section 6.1). Therefore this Section does not discuss specific administrative issues related to S&P/S-SHP, but mainly the economic facilitation.

8.2.1 Remuneration instruments for storage and pumped-storage SHP

The current institutional framework offers some remuneration instruments but which were not developed to facilitate RETs which can provide flexible production and energy storage. Therefore, additional instruments aligned to the RET facilitation schemes have been identified and developed in this research.

The Federal Energy Strategy 2050 mentions that new market rules for peak and balancing electricity have to be set up within the changing electricity sector (BFE, 2011c). The IEA recommends incorporating instruments into the market that enable sufficient flexibility in response from supply- and demand-side to harness intermittent RETs (IEA, 2011). Instruments may not only relate the prices to the market, but also include fixed price schemes. The challenge for policy makers is therefore finding the right balance between market and planned approaches (Steggals, Gross et al., 2011).

[247] Meeting with the SFOE, Bern, 05.12.2011.

In many countries, additional incentives such as remuneration instruments are necessary for deploying sufficient storage capacities to meet RET targets (Pieper and Rubel, 2010). In Switzerland, however, large storage and pumped-storage hydropower plants could provide energy storage and flexible production and be used for the integration of intermittent RETs at the local and regional level. In this case, such large hydropower plants should receive additional remuneration for their contribution towards RETs integration within the RET facilitation schemes as they deal with the perturbation in the grid caused by the intermittencies[248]. However, large storage and pumped-storage hydropower plants should be used for the large scale integration of intermittent RETs within a national and continental perspective.

In the case of S&P/S-SHP, a differentiation between storage and pumped-storage plants has to be made. Storage plants belong to the RETs, but pumped-storage plants are only part of RETs if the pumping energy comes from RETs as well. In some cases this is possible (see remuneration instruments "regional integration of intermittent RETs"), but in most cases electricity from RET is used by consumers and not for pumping water up which leads to additional losses in the production cycle. Therefore, pumped-storage SHP which pump with electricity from non-RETs have to be remunerated with instruments outside of the RET facilitation schemes. If there are natural inflows in the upper reservoir, pumped-storage SHP plants can differentiate their production between renewable (i.e., natural inflows) and not-renewable (i.e., pumped water with electricity from not-RETs) and thus benefit from RET remuneration schemes[249].

In Europe, only Portugal, Germany and the Czech Republic have remuneration instruments taking into account flexible production. In Portugal, the feed-in tariffs depend on the time of electricity production (i.e., peak/off peak) (Haas, Panzer et al., 2011). In Germany, the market premium model introduced in 2012 accounts for the flexible production of hydropower (Walter, Munz et al., 2012). In the Czech Republic, the guaranteed tariff differentiates between run-of-the-river and storage plants in peak or semi-peak production[250]. The additional income for peak and semi-peak production is 25%.

It is not the scope of this research to compare in depth the different instruments below, but to identify and develop some remuneration instruments which would facilitate the economically viable development of storage and pumped-storage SHP. Such remuneration should allow enough income for the environmental integration of the storage capacities as well. The first round of the interviews discussed adaptation to the FIR scheme and identification of some other instruments (e.g., regional integration of intermittent RETs). In the second round, specific instruments were discussed (e.g., spot market, decentralised ancillary services). Finally, further instruments were developed by the author during the analysis. These instruments would not only facilitate new S&P/S-SHP projects, but also enable the operation of existing S&P/S-SHP plants in providing flexible production. Some remuneration cost figures are given at the end of this Section.

Before introducing the instruments below, the concept of "virtual power plant" needs to be introduced as the analysis below refers to it. A virtual power plant is an aggregation and network of distributed plants creating a provisional interface to exploit technical and economic synergies (Eurelectric, 2011). The virtual power plant is managed centrally. In the case of SHP plants on same streams, the operation of one plant should not compromise the operation of another plant, but the whole network of the SHP plants should be optimised technically and economically. In the case of several plants within close distance, the electrical synchronisation with the grid could also be operated centrally.

[248] Interview VS-7

[249] To account for the difference between RET and not-RET production of a pumped-storage plant, the same methodology as for large hydropower can be used. The electricity used for the pumping is multiplied by the overall efficiency factor of the pump-turbine cycle (currently 83% in the Swiss electricity statistics) to calculate the produced electricity with the pumped water. The overall production of the plant minus the produced electricity with the pumped water gives the electricity production from the natural inflows.

[250] http://www.streammap.esha.be/29.0.html (accessed on 01.09.2011)

Table 8-15 shows the existing remuneration instruments for S&P/S-SHP which are discussed below. New instruments follow afterwards.

Table 8-15: Existing remuneration instruments for S&P/S-SHP (alphabetic order)

Instrument	RET / not RET	Storage / Pumped-storage	Application to SHP	Source
Ancillary services	Not RET	Both	Plants above 5 MW can contribute to the tertiary control.	www.swissgrid.ch
Contract with electricity distributor	RET	Storage, ev. Pumped-storage	Plants receive a remuneration defined with an electricity distributor selling electricity from RETs.	Interview VS-7
FIR – scheduled production	RET	Storage	Plants produce according to a schedule determined in advance and receive a corresponding FIR.	Electricity Supply Ordinance (14.03.2008)
Local power balancing	Not RET	Both	Plants contribute to the local power balancing especially within multipurpose infrastructures.	Interviews VS-4 and VS-6
Spot market	Not RET	Both	Plants above 0.1 MW sell their electricity on the spot market.	www.eex.com

Ancillary services

Switzerland is one control region within the electricity grid in Europe[251]. The power flows between supply and demand have thus to be balanced within the national borders which is what ancillary services ensure. These services are delivered by the TSO, Swissgrid, in addition to the transmission of electricity.

Ancillary services include frequency control (primary control, secondary control, and tertiary control), voltage support, black start, system coordination, etc.[252]. The services are used for example in the case of failure of a power plant or a major consumer to cover for missing or excess electricity. In such cases, Swissgrid contacts the producers with which it concluded an agreement in advance. These producers then perform their agreed service, i.e. either increasing or decreasing their electricity production. The agreements are reached following tender processes[253].

The costs paid by the consumers for the ancillary services are 3.8% of the overall electricity price (Swissgrid, 2011). Even though this amount is small, the opportunity costs for power plants to contribute towards ancillary services can be financially rewarding depending on the technology, the time of year, hour of the day, storage capacity and electricity market price.

S&P/S-SHP can contribute to frequency control whereby only tertiary control is possible where the tenders are for blocks of four hours (for primary and secondary control the tenders are weekly). The minimum installed capacity is +/- 5 MW, whereby the additional increment is 1 MW (Swissgrid, 2010). The capacity must be available 15 to 34 minutes after contact with Swissgrid. Capacity can be submitted for tertiary control without participating at the capacity tender in which case only the delivered electricity production is remunerated and not the availability of capacity.

[251] https://www.swissgrid.ch/dam/swissgrid/experts/bgm/bg_documents/de/D110620_balance_group_model_intro_de.pdf (accessed on 03.10.2011)
[252] https://www.swissgrid.ch/swissgrid/en/home/experts/topics/ancillary_services.html (accessed on 02.09..2011)
[253] https://www.swissgrid.ch/dam/swissgrid/experts/ancillary_services/Dokumente/D110524_AS-Products_V6R1_DE.pdf (accessed on 02.09.2011)

To be used as remuneration instruments for S&P/S-SHP plants, the remuneration for ancillary services has to be higher than the production costs plus the costs related to the online measurement of the electricity flows at the plant, the data transmission and the securing of the reachability of the plant operator. Swissgrid calculated in an internal evaluation that the remuneration for tertiary control reaches only a maximum of half of the current FIR for the same installed capacity for a SHP plant[254]. However, should the prices for the remuneration of ancillary services significantly increase, then SHP plants currently receiving the FIR could sell part of their production as ancillary services. The office of the ElCom states that SHP plants can sell on call tertiary control energy if they do not sell the same electricity under the FIR scheme[255].

Swissgrid evaluated the possibility of virtual power plants for ancillary services, especially tertiary control[256]. It allows several plants below 5 MW to tender as a virtual plant and reduces the transaction costs. However, the administrative efforts are significant. In the near future, such virtual power plants will not be an alternative for tertiary control to the existing large scale plant, but a complement (Burger, 2011). In certain cases, where the production costs of a virtual power plant reach competitiveness with large power plants tendering for tertiary control, such plants may contribute towards ancillary services. Otherwise, ancillary services are currently not an option for the remuneration of S&P/S-SHP.

With the development of the smart grids, however, opportunities for decentralised ancillary services could arise. S&P/S-SHP could therefore contribute at the local and regional level to power and energy balancing. If the electricity sector becomes more decentralised technically, then it has to become more institutionally decentralised as well in order to ensure coherence (see coherence of coordination mechanisms in Section 3.3.2). Thus decentralised ancillary services should be introduced (see below).

Contract with electricity distributor

An electricity distributor which aims at supplying electricity from RETs to its customers signs a contract with an S&P/S-SHP plant operator. The remuneration within the contract takes into account the flexible production. In the case of pumped-storage SHP, the pumping energy has to come from other RETs.

The electricity distributor makes it clear within its marketing strategies that it supplies not only electricity from RETs to its customers (i.e., quantity), but also that the RETs contribute to cover the demand fluctuations (i.e., "quality"). No example of such a contract was found during the research.

FIR – scheduled production

The Electricity Supply Ordinance states in Article 24, second alignment[257], that RETs, which can control their production, can benefit from a FIR based on a defined schedule. The yearly average FIR has to be at least the same amount than the FIR defined in the Energy Ordinance for plants not operating on schedule (i.e., standard FIR)[258].

This FIR on schedule production is not yet used[259]. Nevertheless, it could be used to shift production to be more aligned with the demand rather than increase the income of a plant.

If a pumped-storage SHP plant wants to receive the FIR in the current scheme, it has to clearly differentiate between natural inflows accounting for renewable production remunerated by the FIR, and the production thanks

[254] Personal communication with Swissgrid, 03.02.2011.
[255] Personal communication with the office of the Elcom, 16.05.2011.
[256] https://www.swissgrid.ch/dam/swissgrid/experts/ancillary_services/prequalification/D110307_Pooling-of-tertiary-control-units_V1R3_DE.pdf (accessed on 02.09.2011)
[257] http://www.admin.ch/ch/d/sr/734_71/a24.html (accessed on 01.02.2012)
[258] http://www.admin.ch/ch/d/sr/730_01/app1.html#ahref0 (accessed on 02.01.2011)
[259] Interview CH-4 and personal communication with SFOE 16.11.2011.

to pumping which has to be remunerated outside the FIR scheme. No pumped-storage SHP is yet receiving the FIR[260].

Local power balancing

In the case that a local electricity distributor is a multi-services utility and also has own production plants (e.g., utilities of cities), such plants can be used for the power balancing at the local level. S&P/S-SHP schemes built with existing or planned infrastructures and plants could thus be financially viable as they would provide flexibility in production. This could contribute towards reducing penalty fees linked to power balancing.

The remuneration of S&P/S-SHP as part of local power balancing is only interesting if the installed capacity of the S&P/S-SHP plants is in a similar range than the average forecasted capacity error between the demand and supply[261]. In addition, power balancing with SHP is only feasible with a certain size of the utility. For example, it must be ensured that plants can be operated not only during working hours, but also on weekends and during the night. This is becoming increasingly possible thanks to automation and ICT. The benefit of an internal power balancing has to be clearly determined in advance, otherwise it is more reliable and cheaper to outsource the power balancing and pay for it from an external supplier[262].

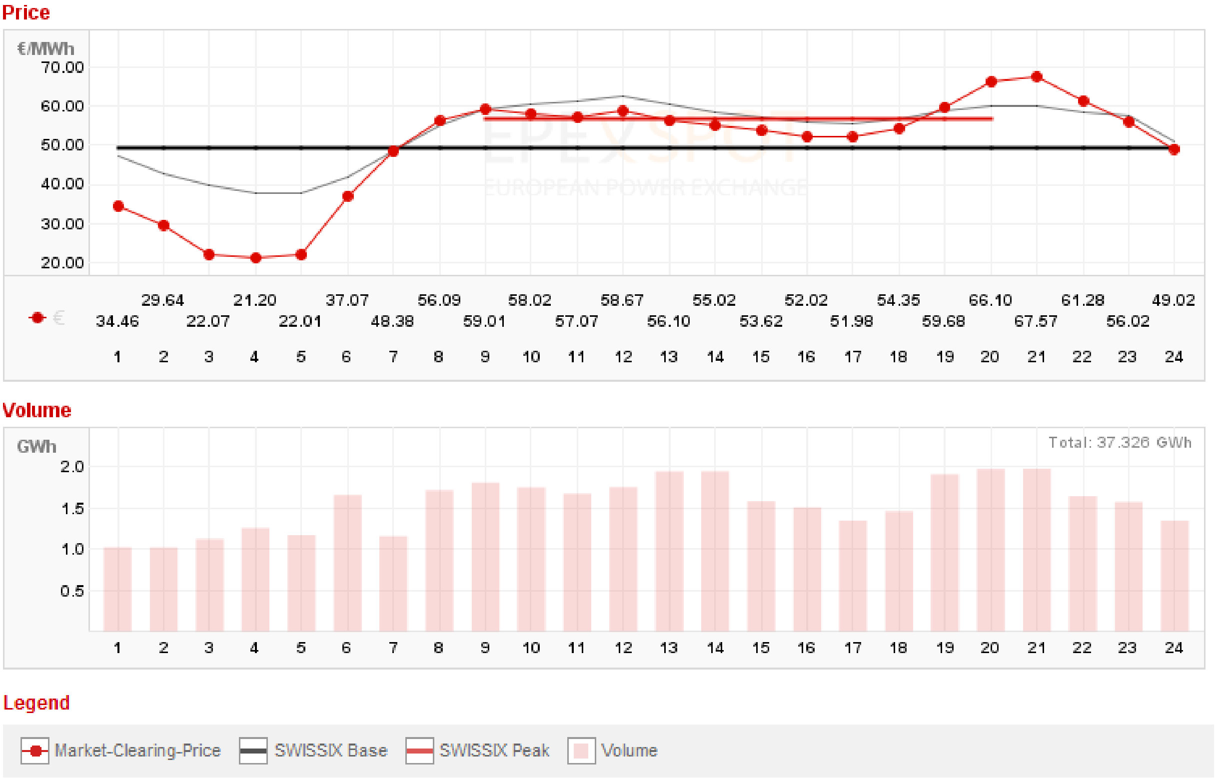
Spot market

The spot market is part of the electricity trade market (see Figure 2-2). On the spot market, electricity is traded short term for the same or the next day. It serves to balance short term changes in production and demand. The scheduling in electricity planning will become shorter to hours or even smaller periods of time and require plants that can adapt very quickly to the demand (Teller, Kunz et al., 2011). The prices are very volatile and depend mainly on power plants availability, temperature, rain, level of storage and cross-border trading (Leimbacher, 2008). Daily, monthly and seasonal cycles can be observed.

The trading can currently be done per hour or per block[263]. The specific regulations can be found on the website of EEX[264]. The minimum installed capacity for the trading is 0.1 MW and for cross-border trading 1 MW (EPEX, 2010).

The traded electricity on the Swiss exchange platform SWISSIX represented 10% in 2008 and 14% in 2010 of the total electricity production[265]. The traded amount grew from 6.1 TWh in 2008 to 9.3 TWh in 2010 (i.e., +50%). The price varies during the day (see Figure 8-2), but the traded amounts are more stable across the day.

260 Personal communication with SFOE 16.11.2011.
261 Meeting with Olivier De Marignac, SIL, Lausanne, 09.12.2011.
262 Interview VS-6 and Meeting Sinergy 21.02.2011.
263 http://www.epexspot.com/en/product-info/auction/switzerland (accessed on 02.09.2011)
264 http://www.eex.com/en/Download/Documentation (accessed on 02.09.2011)
265 http://www.eex.com/de/Marktdaten/Handelsdaten/Strom/Stundenkontrakte%20|%20Spotmarkt%20Stundenauktion/Stundenkontrakte%20Chart%20|%20Spotmarkt%20Stundenauktion/spot-hours-chart/2008-12-31/SWISSIX/-/1y (accessed on 02.01.2011)



Remark: SWISSIX Peak is one of the possible trading blocks.

Source: www.eex.com, Market Data, accessed on 20.01.2012

Figure 8-2: SWISSIX Spot market prices and traded volumes on the 02.09.2011 with average hour prices during the previous 200 days (light black line)

As an example, Figure 8-2 shows that the spread during a day can reach 50 € cts/kWh. However, on average over a longer period of time (light black line in Figure 8-2), the price differences between peak and off peak hours are currently not significant enough to remunerate pumped-storage SHP plants adequately. The reference cases in Section 8.1.2 are evaluated with five hours of production and seven to ten hours of pumping. The price differentiation between the production and pumping hours remains too small to remunerate such plants (see Table 8-11). However, storage SHP plants could in some cases be financial viable by selling their production at highly priced hours. In the future and with smart grid developments, regional spot markets could be developed in which S&P/S-SHP would be more competitive.

The projections on the price evolution on the spot market are very uncertain. Using the trends of the past years, it is likely that the differences between low and high prices are going to remain stable for the next few years (Plaz and Hanser, 2008). However, the current dynamics in the electricity sector may change this.

The administrative fees, composed of a fixed annual fee and variable fees depending on the amount of electricity traded[266], have to be added to the production costs of an S&P-S-SHP plant when trading on the spot market. In order to reduce transaction costs per kWh traded several plants can be combined together to become a virtual plant when interacting with the spot market.

[266] http://static.epexspot.com/document/11454/Price_List2011.pdf (accessed on 02.01.2011)

Table 8-16 shows identified new and adapted remuneration instruments for S&P/S-SHP which were developed during the analysis. A more detailed description per instrument follows below the Table.

Table 8-16: New and adapted remuneration instruments for S&P/S-SHP (alphabetic order)

Instrument	RET / not RET	Storage / Pumped-storage	Description	Required adaptations
Ancillary services – green services	RET	First storage, then pumped-storage	Based on the percentage of electricity from RETs in the electricity mix, at least the same percentage is asked from RETs for ancillary services.	Introduce the same quota of electricity production from RETs to the amount of electricity from RETs used for ancillary services.
Ancillary services – regional/local approach	Not RET	Both	Distributed plants contribute at lower voltage level to ancillary services.	Implement decentralised ancillary services from distributed plants within smart grid developments.
CO_2 compensation scheme for peak and flexible production	RET	Storage	CO_2 compensations for emissions during peak or flexible demand are traded separately from the base compensation.	Create a separated trading scheme for CO_2 compensation generated by peak or flexible production.
FIR – peak premium	RET	Storage	A premium is paid for producing during peak demand.	Adapt the existing Federal Energy Ordinance for the FIR (Appendix 1.1)[1].
FIR – regional integration of intermittent RETs	RET	Both	Intermittent production units have to provide regional storage capacities to align production to the demand.	Set up decentralised “Bilanzgruppen Erneuerbare Energien”[2].
Labelled green electricity – quota for peak production	RET	Storage	Customers buying labelled green electricity have to be supplied with peak labelled green electricity as well according to their consumption profile.	Adapt the current market for labelled green electricity to account for peak production as well.
Sustainable alpine mobility – internal remuneration	RET	Pumped-storage	Ski resorts use their infrastructure to produce electricity from RETs to cover their demand.	Exploit the pumped-storage SHP potential within artificial snow making infrastructures.

[1] *If the peak production can be scheduled, then no need of changing the Ordinance, but just establish a new guideline for the implementation of Art. 24 of the Energy Supply Ordinance (see above “FIR – schedule production”).*

[2] *The law allows it already (Interview CH-4).*

Ancillary services – green services

The deployment of RETs due to the institutional facilitation has an impact on the system management of the electricity sector (see Section 3.3 concerning system management). Among the affected services are the ancillary services. In order to be coherent within the RETs facilitation and based on the percentage of electricity from RETs in the electricity mix, the same percentage could be asked from RETs for ancillary services. The percentage for green ancillary services could even be increased as intermittent RETs require more ancillary services than conventional production.

Looking into the future, RET targets would not only be applied to quantities of production, but also to ancillary services. The higher costs for the ancillary services from RETs would be transferred to the customers consuming electricity by institutionally facilitated RETs, i.e. customers buying labelled green electricity, as well as customers paying the FIR. The costs would be proportional to the consumption of each customer, therefore linked to the price per kWh.

Green ancillary services could be introduced for storage SHP plants. Pumped-storage SHP plants come into consideration once an important penetration of intermittent RETs has occurred and can pump water up when not consumed otherwise. If this is only locally the case, green ancillary services would have to be developed as local ancillary services (see next point).

Instead of S&P/S-SHP and in order to be more economic, large storage and pumped-storage hydropower could be included with the RETs providing green services. However, that would leave the category of the RETs institutionally facilitated.

Ancillary services – regional/local approach

Distributed plants contribute towards stabilising the network and reducing congestions. They should be remunerated accordingly[267] as they contribute to an optimised operation of distribution networks (Eurelectric, 2011). Linked to the smart grid developments, decentralised ancillary services could be developed at the local and regional levels. It would be in line with the coherence from the geographical scope perspective (see Section 3.3.1), i.e. the institutional operational rules of the electricity grid would be aligned with the technical operations of the grid within a given geographical scope. Distributed plants such as S&P/S-SHP plants could contribute to such decentralised ancillary services. Plants with synchronous generators can contribute towards voltage control and in the case of upgrading generators towards frequency control as well (Berizzi, Papetti et al., 2011). Even run-of-the-river SHP plants could contribute towards ancillary services and a study in Italy showed that the remuneration would have to be about 3% more than the current feed-in tariffs (Berizzi, Papetti et al., 2011). The remuneration would come from the services provided within the regional/local grid and could be mainly a function of installed capacity and production hours a year.

However, as long as the distributed generation at low voltage level within a distribution network is significantly lower than the consumptions, the current ancillary services managed by the TSO are the better solution[268]. In the next decades, cogeneration and photovoltaic plants could considerably increase distributed generation and thus create the need for decentralised ancillary services. Should the installed capacity of intermittent distributed RETs become higher than the average gap in forecasted demand and supply within a distribution network, then decentralised ancillary services would also become necessary[269]. Decentralised ancillary services would then require the upgrading of the distribution network in order to have real-time data on the power flows (e.g., within smart grid developments).

CO_2 compensation scheme for peak and flexible production

When thermal power plants compensate their CO_2 emissions (see Section 6.6), they should compensate according to their production profile. The differentiation between base and peak load should not only be technical (i.e., time of feeding into the grid), but also institutional (e.g., CO_2 compensation). Peak CO_2 emissions should be compensated by peak CO_2 credits. The same accounts for base emissions and credits, as well as for flexible production. It would therefore not solely be a compensation scheme taking into account the quantity of kWh

[267] Interviews CH-10, VS-4, VS-5, VS-6 and VS-7.
[268] Meeting with Olivier De Marignac, SIL, Lausanne, 09.12.2011.
[269] Meeting with Olivier De Marignac, SIL, Lausanne, 09.12.2011.

produced, but also the moment of production. Such a CO_2 compensation scheme would lead to more peak and flexible production from RETs, thus reducing the amount needed from thermal plants to cover the peak and flexible demand.

FIR – peak premium

The premium would be part of the FIR scheme and paid for production during peak demand. It would reflect the value of the produced peak electricity. The premium could be linked to the Swissix spot market price, the numbers of yearly production hours and/or regularity in production (e.g., daily 2 hours over lunch). The premium FIR should cover the environmental integration of the storage capacities. Among the interviewees asked about the FIR – peak premium, seven supported it[270], two were against it[271] and two saw the implementation as being difficult[272]. One of the latter, receiving himself the FIR for several SHP plants, highlighted the fact that there were significant errors with the FIR payments made by Energiepool in 2009 (see Table 6-3). The interviewee was in favour of keeping the FIR scheme as simple as possible by not adding premiums for peak electricity. He suggested instead the use of the scheduled production for FIR (see above).

An alternative is to change the current premium-fix FIR scheme to a premium FIR for all RETs, independently of their ability to produce with flexibility. Premium FIR schemes give plants producing with RETs an additional premium on the market price, instead of a fixed remuneration. The market price being variable, the overall price received by the plants is variable as well. Such schemes favour plants which can adapt their production to the market price (Steggals, Gross et al., 2011). It would thus be in favour of S&P/S-SHP plants.

A further alternative is to penalise intermittent RETs by introducing a deduction to the FIR depending on the uncertainty in the production[273]. The deduction would be linked to the costs of the ancillary services necessary for the integration of these intermittent RETs receiving the FIR.

FIR – regional integration of intermittent RET

Intermittent production plants should provide storage capacities for time and load shifting[274]. They could be combined with S&P/S-SHP plants within the region to common schemes (e.g., virtual power plants) to adjust production to the demand. The inclusion of controllable production units would compensate the unreliability/unpredictability of the other RETs.

The regional approach enables the development of local acceptance and ownership of the RET plants, thus reducing oppositions. If there is local consumption of electricity from a local infrastructure having a local impact on the environment, the opposition is likely to be reduced. In addition, the regional approach allows optimisation of the combined schemes based on the meteorological forecasts (Dierer, Remund et al., 2010).

The additional costs for the storage could be covered within an adapted FIR scheme. Currently, the FIR is accounted for through the “Bilanzgruppe Erneuerbare Energien” (see Section 5.2.2). With developments leading to more local and regional operation of the grid, such balance groups for RETs could be set up in a decentralised way. The common schemes of several RETs would be remunerated according to their production which, thanks to storage capacities, would be aligned to the local and regional demand.

[270] Interviews CH-2, CH-6, VS-1, VS-4, VS-6, VS-7 and VS-8
[271] Interviews CH-10 and VS-5
[272] Interviews CH-3 and CH-9
[273] Meeting with the SFOE, Bern, 05.12.2011.
[274] Interviews CH-10, VS-4, VS-5 and VS-6

Alternatively, such balance groups regrouping several RET plants interacting as a virtual plant with the electricity market could also be set up beyond regional scope[275]. For example, in the case of Switzerland, a virtual plant could regroup wind power plants from the Jura with photovoltaic plants in the Ticino and S&P/S-SHP in the Alps. The optimisation of production with weather forecasts would thus happen on a larger geographical scale.

Labelled green electricity - quota for peak production

When customers buy labelled green electricity (e.g., Naturemade and TÜV), some peak production from labelled RET plants should be included in the package according to their consumption profile (base/peak). Otherwise, customers can consume peak electricity which technically is not from RETs and thus not labelled, even though they pay for labelled green electricity. A quota for peak production ensures the coherence between the technical side (i.e., production profile of the electricity) and the institutional side (i.e., accounting of the labelled electricity). The quota for peak labelled green electricity would be the same as the ratio between the peak consumption and the base consumption of each customer. With the development of the ICT to measure electricity flows, the data collection to calculate such quotas becomes feasible. The quota could be defined over a year in order to establish profiles of the different customers and produce accordingly labelled green peak electricity.

Sustainable alpine mobility – internal remuneration

Ski resorts could significantly increase the use of their infrastructures to produce renewable electricity[276]. Aiming at sustainable mobility within the resorts, the electricity for the artificial snow making and all transport means for the tourists could come as much as possible from RETs. As developed previously, water in artificial snow making reservoirs can be used within pumped-storage schemes when not needed for artificial snow. Such pumped-storage plants would allow flexible production for the ski resorts. Other RETs such as solar panels on all pylons and roofs of the ski resort infrastructures could provide the pumping energy when their electricity was not otherwise consumed.

The aim is to produce the amount of consumed electricity for artificial snow making and transport over the year. Therefore, in summer, electricity not used in the ski resort would be fed into the grid (which can be flexible production) and in winter electricity would be consumed from the grid. Over one year, the ski resort would try to cover as much as possible its electricity demand with RET production from its infrastructure and communicate this within its marketing strategies. The marketing goal is to be seen as a ski resort which provides sustainable alpine mobility (including use of the infrastructure in summer for the hiking tourists).

Remuneration cost estimates

From the reference cases (see Table 8-11) first rough estimates on the pricing for the remuneration instruments can be derived. Using existing plants and infrastructures the additional costs for storage plants can remain low (below 10 cts/kWh). Storage SHP plants could therefore be easily constructed if the financial remuneration became more attractive than producing as a run-of-the-river plant.

For pumped-storage SHP plants, the production costs of the cheapest reference cases are between 20 and 30 cts/kWh taking into account 8 cts/kWh as pumping costs. These costs are in the range of the FIR for MHP and photovoltaic. As the institutional framework facilitated such plants with high production costs, pumped-storage

[275] Meeting with the SFOE, Bern, 05.12.2011.
[276] Interview VS-4 and Meeting with CMA, Montana, 19.01.2011.

SHP plants contributing to flexible production and energy storage should be institutionally facilitated as well, and thus, adequate remuneration instruments implemented as developed above.

The current estimates of the cost figures and required remunerations are limited by the amount of reference cases. In addition, these cases have to be further developed and projects constructed before being used as reference plants for defining the adequate remuneration figures. Thus, the current estimates can be used as indications to show the economic competiveness compared to the costs of other RETs not providing flexible production.

8.2.2 Dynamic residual flow regulation

The current residual flow regulation presented in Section 5.2.2 defines a constant value for the residual flow in the river section downstream of the water intake. However, in natural streams, the flow is not constant.

SHP plants release the minimum residual flow whilst operating below or equal to the maximum installed capacity. When the flow in the stream is above the maximum equipped flow, and the production is at maximum capacity, more than the minimum residual flow is released into the stream. This does not reflect the river dynamic in its original status. Therefore, more differentiated regulation should be introduced which optimises the ecological value of the river and the electricity production, as well as the flood mitigation. It could be achieved by dynamic residual flow with fluctuation on a daily and/or seasonal basis[277].

A seasonal dynamic would take into account certain periods of the year when more water should be released into the stream, and, during other months, the current minimum residual flow value could be reviewed and decreased. The aim is to follow annual natural flow fluctuation more closely in operating a SHP plant. The idea has been partly developed within the greenhydro standards (Bratrich and Truffer, 2001) and other previous research[278].

Daily dynamics could be linked with producing energy for peak demand periods. More water would be released into the stream during certain hours, while less would be released during peak hours of electricity production. This could partly reflect flow dynamics for streams downstream of glaciers where natural daily cycles exist. The optimisation should be based on a multi-criteria approach, i.e. technical criteria (e.g., maximise peak hour production to cover the demand), ecological criteria (e.g., flows in the river as natural as possible) and financial criteria (e.g., economic optimisation). Daily dynamics would increase the flexibility in operating SHP plants, especially in the case of storage plants.

Some interviewees were critical to this idea[279]. Their main preoccupation was the complexity of implementing dynamic regulation. Already today the administrative procedures are long and complex, including agreements on the correct minimal residual flow. Making this flow dynamic adds additional complexity. The author, however, sees opportunity with ICT for automation in the operation of plants with dynamic minimum residual flow. Defining the daily and/or seasonal dynamic flows remains a topic for further research.

In order to introduce dynamic residual flows which would be below the minimum currently required by the law during certain periods of the day, it would have to fall under the criteria for exceptions stipulated in the Water Protection Law (Art. 32, c, see Section 5.2.2). In order to widely introduce dynamic residual flows, the Water Protection Law would have to be modified (Art. 31 or Art. 32). Furthermore the residual flow regulation has to be in line with hydropeaking regulation (see Section 5.2.2).

[277] Interviews CH-1, CH-6, CH-9, CH-10, CH-11, VS-4, VS-7 and VS-8
[278] Interview CH-10
[279] Interviews CH-10 and VS-5

An alternative to dynamic residual flow values going below the current legal minimum is to define residual flow values with a regional zone perspective instead of a single stream perspective[280]. The idea would be to optimise the hydropower use and the environmental protection within the zone instead of for a single site. This could be developed within Cantonal hydropower master plans (see also Section 6.1).

Conclusion

The technical potential of storage and pumped-storage SHP in Switzerland is important compared to the existing installed capacities as shown in Table 8-14. The installed capacity of storage SHP could be increased from 106 to 200-300 MW; the one of pumped-storage from 15 to 70-150 MW. Furthermore, the identified potential is with existing and planned plants and infrastructures thus adding value to them. The technical potential of storage schemes lies mainly with plants on streams. With the introduction of the FIR, the number of such plants will continue to increase and thus offer opportunities for storage applications as well. The technical potential for pumped-storage schemes is found mainly within existing and planned infrastructures. Water can be used within closed systems for pumped-storage before being used for its final purpose (e.g., snow, irrigation water).

S&P/S-SHP should be one of the technologies institutionally facilitated within storage RET policies. Thus, the institutional framework facilitating RETs should include adequate remuneration instruments. The instruments vary between storage and pumped-storage and include green ancillary services, peak and flexible CO_2 compensation, premiums for peak production in the existing FIR scheme, etc. The additional costs to cover for storage SHP plants compared to run-of-the-river plants are below 10 cts/kWh on the reference cases. In the case of the identified pumped-storage plants, the spread between selling and purchasing electricity is about 10-20 cts/kWh.

In conclusion, S&P/S-SHP plants have a clear potential worth facilitating and developing in Switzerland. Further research should improve the quantitative evaluation of the technical potential and develop in more detail the remuneration instruments. Furthermore, reference cases could be developed into real projects and thus become reference plants leading the way to further deployment of S&P/S-SHP plants.

[280] Interview CH-11

9. Conclusion and recommendations

The Federal Energy Law defines targets for increasing the importance of renewable energy technologies (RETs), including small hydropower (SHP) (see Section 2.2.3). Following the Federal government and parliament decision in 2011 to phase out nuclear power, which today provides approximately 40% of the domestic electricity production, the Swiss energy policy is being reviewed. The government aims to increase further the production from SHP.

SHP is a well developed RET which, compared to other RETs, has higher energy efficiency in using the primary energy source and, on average, lower production costs (see Section 4.1). Furthermore, it can be combined with other infrastructures such as drinking water, irrigation and artificial snow making infrastructures.

SHP is one of the generation technologies in the electricity sector. This sector is evolving with the liberalisation process which brings changes to the institutions (i.e., the rules of the game according to North – see Section 3.1). The literature on co-evolution and the framework of coherence between institutions and technologies in the case of network industries, such as electricity, contributes towards an analysis of the changes and their effect. As it had never been done before, this literature and in particular the coherence framework were used in this research to analyse the coherence between institutions and the technology in the case of SHP, taking into account the above considerations on increasing the SHP production and the liberalisation process. It is mainly the institutions that have to further evolve. The technology could evolve in regards to storage and pumped-storage SHP which was identified as an opportunity for the further SHP development.

This Chapter takes a look back at the research to compare it with its research objective and a look forward to identify future research opportunities. Firstly, it summarises the key results with recommendations for decision makers and discusses the contribution of the research to the literature.

9.1 Key results and recommendations for decision makers

Policy instruments were identified which should further facilitate the development of SHP in Switzerland. This Section presents the key results for the facilitation of SHP, as well as the argument and instruments to develop storage and pumped-storage SHP (S&P/S-SHP). The specific result of the research, i.e. the technical evaluation of S&P/S-SHP, is also summarised.

9.1.1 Facilitate the SHP development in Switzerland

SHP is mainly facilitated financially today by the feed-in remuneration (FIR) and green tariffs (see Section 5.2.2). Its development is hindered, however, by complex administrative procedures and environmental opposition. Based on the review of the technology, including its potential (see Chapter 4), and its institutional framework (see Chapter 5), the alignment between the technology and its institutional framework was analysed (see Chapter 6). Besides several policy instruments, measures to simplify and harmonise administrative procedures and to guarantee the technical quality of SHP plants receiving the FIR were analysed in more detail.

Some measures to simplify, harmonise and streamline administrative procedures require changes in the legislation which cannot be implemented in the short term. Both the bundling of all procedures into one application dossier and the regrouping of several projects (e.g., in the same river section) applying together for the various authorisations are currently not possible, but could simplify administrative procedures for the project promoters. Linear procedures, instead of the current procedures with several loops with the same authorities (e.g., see Figure 6-1), would contribute towards a streamlining of the procedures. The further evaluation of such simplification and streamlining measures are currently evaluated by the Federal administration following the acceptance of a motion in the Federal parliament in June 2011 and are in line with the Energy Strategy 2050 of the Federal government.

Other measures could be implemented in the short term:

- Electronic applications could be much more developed. A reference interface on the internet could be developed which could then be copied by each Canton[281]. The Cantons could add their documents and specific legislation into the corresponding sections. Projects promoters would then use only one common administrative interface for all projects.
- One-stop offices could be set up in the Cantons which do not yet have such a service for SHP projects.
- Procedural checklists could be established in Cantons with an important remaining SHP potential to help the project promoters to undertake the administrative procedures rapidly and correctly. Such checklists exist already in some Cantons.
- Clear and binding deadlines for the administration are required to streamline procedures.
- The Small Hydro program from the Swiss Federal Office of Energy (SFOE) could be reinforced in order to provide greater advice to SHP project promoters and to banks which would like to support SHP development.
- Methodologies and tools to evaluate SHP projects with multiple criteria (including economic and environmental criteria) in the very early development phase should only contribute to the pursuit of projects for which the main stakeholders are favourable to their construction. These methodologies, such as the one in development at the University of Bern (see Section 4.2.2), and these tools, such as the one developed by the Canton of Valais (see Section 6.1), act as filters for feasible projects and could significantly reduce opposition to projects, thus reducing procedural costs and time. In addition, they could contribute towards a harmonised perspective on the SHP development and regional priorities within spatial planning and within the development of hydropower in general.

The second instrument to be analysed in depth was the efficiency criterion. The current FIR scheme does not include measures to guarantee the technical quality of plants. As the FIR depends on the installed capacity adjusted by the annual production, plants can be financially viable even if there are technical inefficiencies due to poor design. However, the FIR should not facilitate the use of hydropower potential by plants of poor quality. Several options for ensuring quality were assessed. The chosen solution is that of a global criterion of efficiency of the SHP plant (ratio of electric energy generated and available hydraulic energy). If the criterion is fulfilled, the plant receives the FIR. If the plant does not fulfil the criterion initially set at the beginning of operation or later, the owner must further invest to improve the plant to continue to receive the FIR. According to the law, such a criterion could be introduced by the SFOE. The criterion could also be linked to the water concession application in order to cover all SHP plants and not only the ones receiving the FIR.

The other analysed policy instruments are given in Table 9-1 with some policy recommendations. The FIR scheme is undergoing changes and other actors were, and still are, involved in research on this scheme. Therefore, only some changes were discussed in this research (see Table 6-3). Quotas with tradable green certificates (TGCs) and green tariffs were briefly discussed, as well as CO_2 credits. The importance of such

[281] The Cantons are the relevant administrative unit for many institutions (see Sections 1.5 and 5.2.1).

credits will increase with the likely new GCC plants in Switzerland. SHP plants should be able to generate CO_2 credits, which is currently not the case. Alternatively to CO_2 credits, GCC plants could compensate their CO_2 emissions by paying into the fund that finances the FIR scheme. This would reduce the costs for the customers currently paying for the FIR scheme.

Table 9-1: Policy instruments to improve the facilitation of SHP in Switzerland

Instrument & measures	Description & explanations	Recommendations for policy makers
Measures to simplify and harmonise administrative procedures (partly existing)	Methodologies and tools to evaluate the feasibility of SHP projects at a very early stage, electronic applications for the procedures, reinforce the Small Hydro program, one-stop office for all administrative procedures, checklists, clear and binding deadlines for the administration, bundling of all applications into 1 application, grouped projects apply together for the authorisations, linear procedures, etc.	Adapt the legislation where necessary and implement measures in the short term which do not require a change in the law (see Table 6-6).
Efficiency criterion	SHP plants must have a given efficiency to receive the FIR.	Implement such a criterion within the current Federal Energy Ordinance.
FIR scheme (existing)	Improve alignment of remuneration curves to the differences in SHP plants, introduce bonuses on very low head plants, exempt customers who buy labelled green electricity from paying for FIR, etc.	Adapt the current FIR scheme accordingly.
Quota with TGCs	Quota with TGCs can be introduced if RET targets are not reached with the existing policy instruments.	No need for action at the moment in the case of SHP. Quotas with TGCs could be introduced for the time after the FIR scheme.
Green tariffs (existing)	As the FIR scheme is being improved, most SHP projects will be funded through the FIR and not through green tariffs. However, should public administration further increase their demand for labelled green electricity and should the green tariffs become as interesting as the FIR, then some SHP plants will be facilitated by these tariffs.	No public policy change necessary in the case of SHP. Green tariffs could become much more important for the time after the FIR scheme. In the meantime, the owners of labels could reduce the administrative costs for SHP plants which would like to receive the label by introducing “programmatic labelling” (i.e. not labelling each single plant, but reference plants (see Section 6.5)).
CO_2 credits	SHP plants should be able to receive CO_2 credits in order to contribute to the CO_2 compensation of future GCC plants in Switzerland.	Adapt the current legislation accordingly.

9.1.2 Develop storage and pumped-storage SHP

The liberalisation process plus the facilitation of RETs for electricity production by national and municipal governments lead to increased distributed and intermittent electricity production (e.g., from wind power and photovoltaic). This necessitates more energy storage and flexible production capacities within the electricity sector (see Chapter 7). To cope with the intermittency, it would be incoherent to the RETs and climate targets to use non-RET plants. The institutional facilitation of RETs therefore needs not only to consider energy quantity (i.e., production of kWh), but, in order to deal with the intermittency, also, needs to include “quality” aspects. These include the alignment between production and the actual electricity demand thanks to storage facilities and flexible production. Therefore, RETs which can contribute to energy storage and flexible production have to be facilitated adequately.

Among the institutionally facilitated RETs (e.g., FIR), SHP is the only technology that can produce with flexibility and, in the case of storage or pumped-storage schemes, provide energy storage. Such schemes can be developed on streams and within infrastructures. Storage and pumped-storage hydropower remains one of the most efficient technologies to "store" electricity with low GHG emissions and a renewable resource. Small scale schemes have a local and regional importance for operating the electricity grid and are complementary to the large scale schemes. The latter have a national and continental importance in line with the role of electricity hub which Switzerland holds in Europe. Significant potential remains for large pumped-storage schemes and some new plants are currently under construction. In the case of SHP, the potential of storage and pumped-storage schemes had not been evaluated before this research, neither the necessary evolution of the institutional frameworks to facilitate such schemes.

S&P/S-SHP is an example of co-evolution and coherence between institutions and technologies. The institutional changes (e.g., liberalisation and national and municipal RETs targets) lead in a co-evolutionary process to technological changes (e.g., more intermittent and distributed production). Technologies are adapted and developed, such as SHP for storage and flexible production purposes. This technological evolution requires further shaping of the institutions in order to be implemented within the overall institutional framework, which is also necessary from a coherence perspective. It is incoherent just to facilitate the quantity of electricity from RETs without taking into account, for example, the system relevant functions within the electricity sector (see Section 3.3.1). S&P/S-SHP can contribute to the system management, mainly storability, and capacity management, both at the decentralised level. This is in line with the trend towards more decentralisation in operating the grid. Therefore, storage RETs such as S&P/S-SHP have to be institutionally facilitated.

The deployment of S&P/S-SHP plants can be especially encouraged within multipurpose infrastructures and the rehabilitation or expansion of existing SHP plants. On streams, existing SHP plants are in very large majority run-of-the-river plants as they are institutionally facilitated (e.g., FIR scheme). There is thus potential for storage schemes. Pumped-storage schemes have potential in currently used and future infrastructures (e.g., artificial snow making and irrigation infrastructure) and infrastructures which are no longer used for their initial purpose (e.g., former military infrastructure). For the former, the aim is to optimise the use of reservoirs during the period where water is stored but not used for its final purpose (e.g., artificial snow, irrigation) by using the water within closed systems for pumped-storage. The overall intention is to develop S&P/S-SHP with existing and planned plants and infrastructures in order to reduce environmental opposition and investment costs.

The technical potential has been evaluated with a bottom up approach for the Canton of Valais. The Cantonal results were extrapolated for Switzerland. Table 9-2 summarises the results.

Table 9-2: Technical potential of storage and pumped-storage SHP in Switzerland

Potential in Switzerland	**In operation (2010)**			**Additional technical potential**		
	Streams[1]	Infrastructures	TOTAL	Streams[1]	Infrastructures	TOTAL
Storage SHP	106 MW	0	**106 MW**	100 - 190	-	**100 - 190**
Pumped-storage SHP	15 MW	0	**15 MW**	30 - 80	20 - 50	**50 - 130**

[1] *including lakes*

Source: rounded from Table 8-14

The remaining technical potential is very important compared to today's plants. The storage potential lies on streams, where existing plants could be upgraded to storage schemes. The pumped-storage potential is found within infrastructures and with lakes where projects would use the water for other purposes as well. Existing artificial lakes, such as in the case of the Fully plant in Valais, could be used for pumped-storage within rehabilitation projects of existing SHP plants.

The potential has to be compared to large storage and pumped-storage hydropower (see Section 7.1.2). Storage hydropower above 10 MW has an installed capacity of 8.1 GW and pumped-storage hydropower of 1.8 GW. This is clearly not in the same range as the results for SHP. However, as explained in Section 8.1.3, small and large hydropower is complementary. Furthermore, SHP belongs to the RETs already facilitated and thus storage and pumped-storage schemes have to be included in the institutional facilitation as argued above for providing distributed energy storage and flexible production.

The spreads in Table 9-2 are significant because of the assessment methodology. The assessment evaluated several reservoir options (dammed and natural lakes, flood protection, artificial snow making, irrigation, drinking water, and unused military infrastructures). Reference cases were identified which could be developed into concrete projects. Each case was evaluated with an Excel-based tool which included some economic evaluation. The spreads of the evaluation of each reference case were cumulated in the sum for the Canton of Valais and then extrapolated for the evaluation of Switzerland.

The limitations of the assessment methodology are due to its explorative and bottom-up approach. Some potential has been overlooked (e.g., planned artificial snow making infrastructure in small ski resorts, formal military infrastructure which is owned privately but unused; see Section 8.1.3). Furthermore, additional potential will arise due to melting glaciers and new infrastructures. The potential evaluation has to be refined. On streams, a quantitative evaluation is being considered (see Section 8.1.2). Within infrastructures, pilot projects could raise the awareness of the potential.

New S&P/S-SHP projects have to be developed to lead the way for further development. Some projects are financially viable within the current institutional framework. However, most projects require institutional changes which policy makers need to implement. S&P/S-SHP is not cost-competitive in the current electricity market and has to be supported with adequate remuneration instruments within the facilitation of the RETs. The RET facilitation has to take into account all associated costs linked to the increased electricity production from facilitated RETs (e.g., costs for ancillary services).

There are some existing instruments which can remunerate S&P/S-SHP. The FIR scheme includes a possible remuneration according to a scheduled production although currently all plants are remunerated with the same tariff independently of the moment of production. S&P/S-SHP plants can sell their electricity on the spot market, but the spread between peak and off-peak needs to be more important for most plants to offer an adequate remuneration. Finally, S&P/S-SHP plants can contribute to the ancillary services. However, the remuneration is about half of what SHP plants receive through the FIR (see Section 8.2.1). Thus, other remuneration instruments are required.

Table 9-3 summarises the identified remuneration instruments within this research. Some of the instruments should be included within the institutional frameworks facilitating RETs (marked with "RET"). In the case of pumped-storage schemes where the pumping energy does not come from RETs, the instruments have to be included in the overall framework for the electricity sector and not within RETs facilitation.

Table 9-3: Overview of the identified new remuneration instruments for S&P/S-SHP (alphabetic order)

Instrument	RET / not RET	Storage / Pumped-storage	Description	*Recommendations*
Ancillary services – green services	RET	First storage, then pumped-storage	Based on the percentage of electricity from RETs in the electricity mix, at least the same percentage is asked from RETs for ancillary services.	***Policy makers*** *introduce a quota for electricity from RETs providing ancillary services.*
Ancillary services – regional/local approach	Not RET	Both	Distributed plants contribute at lower voltage level to ancillary services.	***Local stakeholders*** *develop decentralised ancillary services within smart grid developments.*
CO_2 compensation scheme for peak and flexible production	RET	Storage	CO_2 compensations for emissions during peak or flexible demand are traded separately from the base compensation.	***Policy makers*** *set up a separated trading scheme for CO_2 compensation generated by peak or flexible production.*
FIR – peak premium	RET	Storage	A premium is paid for producing during peak demand.	***Policy makers*** *adapt the existing Federal Energy Ordinance for the FIR.*
FIR – regional integration of intermittent RETs	RET	Both	Intermittent production units have to provide regional storage capacities to align production to the demand.	***Private actors*** *set up decentralised "Bilanzgruppen Erneuerbare Energien" and* ***policy makers*** *adapt the FIR to remunerated virtual plants as well (i.e. several RET plants together).*
Labelled green electricity – quota for peak production	RET	Storage	Customers buying labelled green electricity also have to be supplied with peak labelled green electricity according to their consumption profile.	***Owners of labels*** *(e.g. Naturemade) adapt the current market for labelled green electricity to account for peak production as well.*
Sustainable alpine mobility – internal remuneration	RET	Pumped-storage	Ski resorts use their infrastructure to produce electricity from RETs to cover their demand.	***Owners of artificial snow making infrastructures*** *exploit the pumped-storage SHP potential within their infrastructures.*

Source: adapted from Table 8-16 (new is the right column in italic)

Beside remuneration instruments, the residual flow regulation has been discussed in the research (see Section 8.2.2). The current residual flow regulation defines a constant value for the residual flow in the river section downstream of the water intake. However, in natural streams, the flow is not constant. Dynamic residual flow regulation has been discussed as it would allow more flexibility in the operation of S&P/S-SHP plants. The dynamics would be daily and/or seasonal and account for the optimisation in electricity production and in safeguarding the ecological value of the stream. Nevertheless, residual flow regulation is complex and further discussions within policy making are required.

In conclusion, S&P/S-SHP has a potential worth developing in Switzerland. The institutional facilitation has to take into account not only the electricity quantity from RETs, but their contribution to flexible production and energy storage as well.

9.2 Contribution to the coherence literature

This research contributed to three bodies of literature – mini and small hydropower, the facilitation of renewable energy technologies and the coherence framework. The thesis reviewed the current state of SHP in Switzerland from its technological (e.g., technology description, innovation trends) and institutional perspective. The latter concerned mainly the institutional framework (e.g., legislation, policy instruments). Furthermore, the SHP history in Switzerland was recounted and the SHP potential evaluated (see Section 4.2). Several publications were written, including on the results mentioned in Section 9.1[282].

Some identified and discussed policy instruments are not solely related to SHP, but can concern other RETs as well (e.g., measures to simplify and harmonise administrative procedures, CO_2 credits, quota with TGC). These instruments can be integrated into the facilitation of RETs.

The research contributed to the substantiation of the coherence framework with a concrete illustration, i.e. SHP, and developments on four components of the framework (see Section 3.3.2): Firstly, the unit of analysis was discussed in more depth as the initial publications on the coherence framework remained vague on this point. The unit of analysis has now been defined as the geographical scope for which the performance between institutions and technologies is analysed. Secondly, the network characteristics were introduced (e.g., network topology, capacity constraint). They replaced the system relevant function for defining the specificities of network industries. The functions remain important in the evaluation of the coherence between institutions and technologies. Thirdly, the component “coherence” was renamed “alignment” as alignment better describes how institutions and technologies should relate to each other. However, as the framework is called the coherence framework and the degree of coherence, i.e. alignment, was discussed in the literature, this thesis kept the initial name “coherence” and not “alignment”. Future research will have to develop a more precise definition of alignment. In the meantime, it can be postulated that too much alignment hinders innovation in the technologies and within institutions. However, if there is no minimum alignment, which needs to be defined for each network industry, the system relevant functions cannot be ensured (e.g., some standards (i.e. institutions) which are aligned with the technological choices are required to ensure interoperability in electricity and railways). Finally, the component “performance” was developed into more detail (Crettenand, Laperrouza et al., 2010). Performance became the starting point instead of the result of an evaluation with the coherence framework. As performance was not clearly defined in network industries, the development of the framework tried to add some clarification by defining five performance categories (technical, operational, economic, environmental and social). Actors have to weigh each category to define the performance in a given network industry where they may have conflicting views (e.g., between cost reduction vs. accessibility or reliability, between environmental protection vs. affordability). Ultimately, the key question is who is defining the performance in the end. In network industries, the consumers still perceive the industries as providing an essential service, which is less true for air transport. Therefore, they will influence the government and its public policy objectives through their voting power (especially in Switzerland with its direct democracy). Thus, the key actor defining the performance in a network industry remains the government (Finger, Crettenand et al., 2011).

During the research, findings based on the SHP illustration of the coherence framework were included to further develop the coherence framework (e.g. (Crettenand, 2009, 2011a)). SHP affects only the system management amongst the system relevant functions. SHP can contribute to the controllability and storability as the production can be adjusted in case of storage capacities. In the case of pumped-storage schemes, SHP can also contribute to the “storage” of electricity surplus.

[282] E.g., (Crettenand, 2010; Crettenand and Finger, 2010; Crettenand, 2011b; Crettenand, 2011a; Crettenand and Denis, 2011; Crettenand, Denis et al., 2011). All papers are in the Appendix L.8.

Depending on how the actors define performance, it can facilitate more or less SHP. For example, SHP reduces the transmission losses as it produces close to the consumption site which can favour technical performance; SHP emits almost no GHG emissions which favours environmental performance; but SHP has on average higher production costs than conventional large scale generation which is not supportive for economic performance.

The coherence in the SHP illustration can be evaluated along the four coherence perspectives (see Section 3.3.1). The first two perspectives are merged. Taking the coherence in scope and resolution, the size and scope of institutions have to be coherent with the size and scope of the technology. Thus, SHP should not have to go through the same length of administrative procedures as large hydropower. It has been simplified already, but further evolution is required (as developed above), even though the measures are limited. From the coherence perspective of coordination mechanisms, the question arises to which level institutions have to be decentralised as the SHP technology is a decentralised and distributed technology. Some institutions need to be decentralised and local such as the construction permit, whereas in other cases it is less obvious. For example, should the water concession be granted at the local or regional level. For the latter, it can be argued that the use of water has to be optimised technically and environmentally for a whole river basin and not just at the local level. Another example is the allocation of the feed-in remuneration. If the economic development of SHP is a national policy, then a centralised application and procedures system like today is coherent. But if the economic SHP development is also a local or regional policy, then local or regional institutions have to be set up (e.g., regional feed-in remuneration). Finally, from the coherence in time perspective, the institutions have to be coherent in their duration with the SHP technology. The maximum water concession duration is for example coherent with the technical operating time of a SHP plant.

The concrete illustration with SHP enriched the coherence framework with two specific contributions. Firstly, the coherence has not only to be ensured between the institutions and the technologies, but also within the institutions themselves. For example, a SHP plant operator received the FIR guaranteed for 25 years whereas its water concession was granted for only 20 years. The time durations need to be aligned. Secondly, the coherence must be discussed between the different levels of institutions and technologies, e.g., global, continental, national, regional and local. Institutions are found at each level and so are technologies. In the electricity sector, production can be very local, whereas the grid can be continental and the supply of fuel global. Therefore the coherence at the local level for the production matters, as well as the coherence at the continental level for the operation of the grid. Coherence has thus to be evaluated not solely for the whole network industry within a given unit of analysis, but also at the different levels for the various parts in the industry (e.g., in electricity the generation, transport, distribution and sales).

In conclusion, the coherence framework shaped this research by offering a perspective on how to look at institutions and technologies in network industries, as well as their interaction and co-evolution.

9.3 Concluding remarks on the research

To conclude this thesis, the achieved research compared to the initial objective and research design is reviewed. The limitations of the research are discussed, followed by a description of future possible research opportunities.

9.3.1 Shaping the institutional framework for SHP and limitations of the research

The thesis title indicated that this research was meant to contribute towards shaping the institutional framework for SHP. The research objective was to identify the institutional framework that favours the facilitation of SHP in Switzerland. The objective was reached with the limitations discussed below. Policy instruments were identified and developed which further facilitate the development of SHP (see Section 6). Furthermore, storage and pumped-storage SHP was identified as an opportunity for SHP development. The argument for S&P/S-SHP was developed and changes within the institutional framework necessary to develop such schemes were identified (see Chapters 7 and 8).

The initial research design did not include S&P/S-SHP. The research design was outlined by starting with the context of the research and the theoretical framework. The research was conducted accordingly. The SHP technology and its institutional framework were studied. During the analysis, S&P/S-SHP emerged as an opportunity for SHP within the current dynamics in the electricity sector. Thus, instead of further developing the identified policy instruments for SHP in general, the S&P/S-SHP potential was technically evaluated combined with an analysis of the institutional feasibility. This led to the identification of remuneration instruments for S&P/S-SHP. The focus of the research became storage and pumped-storage schemes. The final research design thus includes an analysis for SHP in general and another on the development of S&P/S-SHP.

It could be argued that more research was still necessary, for example, on the simplification and harmonisation of the administrative procedures and that the analysis on SHP in general should have continued into more depth instead of focusing on S&P/S-SHP. However, the opportunity around S&P/S-SHP looked to be of greater importance to the author than further research on simplification and harmonisation of the administrative procedures could have added to the already existing results. Some simplification and harmonisation measures remain controversial (e.g., changing the laws) and the outcome of further research may not have improved significantly the already obtained results. Further research would have necessitated working in more than one Canton in depth which was not feasible in the given time frame. Furthermore, the review of the administrative procedures was debated in the Federal parliament during the research and the final decision was only reached in June 2011 at the end of the empirical part of the research.

Some limitations of the research were linked to the methodology. Various methods were combined in order to have a methodological triangulation of the research. The limitations of each method were discussed in Section 1.6. The research was also limited by the number of interviews and the survey which only reached the operators of SHP plants which receive the FIR. More interviews could have been conducted, for example with several stakeholders of the same stakeholder category (see Table 5-1). A survey reaching all stakeholders categories or at least all SHP plant owners could have been set up. However, this would have necessitated significant effort on creating the survey whereas the data in this research came from an already prepared survey. Within a longer time frame, more interviews and an additional survey could have been conducted.

The main methodological limitation is given by the unit of analysis. Only one Canton was studied in depth (as argued in Section 1.5) and the results for Switzerland cannot be adopted without adaptation by other countries as the institutional framework in Switzerland is unique (e.g., not EU member, Federalisms, heterogeneous electricity sector).

Concerning the limitations in regard to the results, the policy instruments are mainly linked to SHP and cannot be applied to hydropower in general (e.g., simplification of administrative procedures, efficiency criterion, FIR adaptations). The limitations concerning the simplification and harmonisation of administrative procedures are particular to this research because only one Canton was analysed into more depth. Thus some conclusions cannot be extrapolated to the whole country. Furthermore, it remained difficult to identify simplifications and harmonisation measures requiring changes in the law where a consensus could be reached among the stakeholders within the timeframe of the research.

The main limitations on the other policy instruments are as follows: The value of the efficiency criterion was not defined within this research. This research only summarised current problems with the FIR and possible solutions to it as other researchers were working on it. The instrument for quotas and TGCs was only introduced but not developed in depth as it probably will not be implemented during the next few years. Finally, CO_2 credits for SHP production were identified as a possible policy instrument to be introduced, but no detailed implementation was discussed as the post-Kyoto framework remained very vague during the research.

The limitations of the analysis of S&P/-SHP are given by the explorative approach of the technical potential evaluation, as discussed above, and the identification of remuneration instruments at the conceptual level. The technical potential evaluation gives an order of magnitude, not a precise evaluation. To improve the evaluation concrete projects have to be developed. This would also allow improved calibration of the existing evaluation tool developed within this research. The remuneration instruments are not developed into detail, but remain at the conceptual level (e.g., FIR premium without defining the value of the premium). They show possible directions for further development.

Finally, in regards to the limitations of the research in contributing to the development of the coherence framework, coherence (i.e. alignment) between institutions and technologies still needs to be better defined. More research is needed on the causality between coherence and performance. The framework could then be improved from comparative coherence (i.e., evaluate coherence between institutions and technologies) to design coherence, i.e. helping decision makers to align institutions and technologies according to a defined performance beforehand. The limitations within this research are that the research just added one illustration of the framework and only contributed towards refining some aspects of the framework (e.g., performance, unit of analysis).

9.3.2 Future research

In summary, the possibilities for future research mentioned within this thesis can be developed within the following categories.

Policy instruments in Switzerland

Within the facilitation of SHP, more research is required on the measures to simplify, harmonise and streamline the administrative procedures. Such research is on-going within the SFOE. Future research could contribute towards a definition of the value for the efficiency criterion. Some additional research is also needed regarding the water royalty, i.e. to improve it from its current scheme based on installed capacity to a new scheme more aligned to the real use of the infrastructure (e.g., run-of-the-river, storage). Finally, the remuneration instruments for S&P/S-SHP have to be developed into detail.

S&P/S-SHP potential and development

The technical potential evaluation could be refined with a top-down quantitative evaluation on streams and the evaluation of melting glaciers as future lakes. The potential of interconnected drinking water networks between Communes for S&P/S schemes should be further investigated, in particular, with regards to future interconnection projects. Furthermore, the potential of underground SHP could also be explored. Outside of Switzerland and close to the sea, marine pumped-storage SHP could be studied. The latter could be done within an integrated approach between wind power and SHP development where pumped-storage SHP would contribute towards a remedy for the intermittency of wind power. Finally, the S&P/S-SHP potential could be evaluated in other countries than Switzerland.

Combining the technological and institutional perspective, future research could further elaborate the role that S&P/S-SHP could hold in the future electricity grid. This would include to which degree S&P/S-SHP could contribute to decentralised system management and the importance of S&P/S-SHP for distributed energy storage and flexible production. Furthermore, depending on the penetration of other micro generation plants, the potential of S&P/S-SHP plants below 300 kW could be investigated. More research is also required on dynamic residual flow regulation which would allow more flexibility in operating S&P/S schemes. Finally, future research could adapt the identified remuneration instruments for Switzerland to other countries which would want to support RETs which can produce with flexibility and contribute to energy storage.

Technological development

Future research could develop variable speed pump-turbines for pumped-storage SHP schemes. Alternatively, separate pump and turbine units could be developed striving to improve the energy efficiency of pumped-storage SHP schemes.

Concerning SHP in general, future technological development could reduce the production cost, especially for low-head schemes, with cheaper construction materials, increased reliability, and improved turbines. The environmental integration could be improved with bioengineering and improved passages for fishes, and with measures in regard to the aquatic life and bed load transport. The tele-management of SHP plants could be significantly improved with adequate ICT. Finally, the electromechanical components of MHP could be standardised, thus reduce costs, for plants in countries where water is abundant and the electricity demand only begins to raise.

Coherence framework

In order to upgrade the framework, multiple case studies could be conducted in the different network industries. Within each industry, research would analyse what coherence and what the causality with performance exactly are. Per industry, several case studies would cover the view of the government, regulator, infrastructure manager (i.e. TSO and DSO in electricity), operators (i.e. electricity producers and suppliers), NGOs and customers. The framework should thus become more robust.

Future research could shed light on how less coherence is needed to allow innovation over time and how much is needed to guarantee the safeguarding of the system relevant functions. Future research could also further elaborate on how centralised or decentralised institutions have to or need to be when technologies become more and more decentralised and distributed.

Conclusion

The institutional framework has to further evolve to be aligned with the small hydropower technology. Administrative procedures have to simplified and streamlined. Regional planning has to define the streams for priority SHP development. In addition, the focus of the institutional facilitation of renewable energy technologies should not solely be on increasing the production of electricity, i.e. kWh, but also on facilitating flexible production and energy storage. This integrates intermittent production and contributes to the alignment of the electricity production and demand. Storage and pumped-storage SHP could play an important role for distributed flexible production and distributed energy storage. Its technical potential in Switzerland is significant enough to shape the institutional framework in a co-evolutionary approach.

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Appendix

A. Interview questions – at the national level

La promotion de la mini et petite hydro en Suisse à travers des instruments institutionnels

Questions pour l’interview avec XX, xx.xx.xxxx à X

Questions structurées

1. Est-ce que la liste des instruments est complète? Oui/Non -> compléter
    a. RPC
    b. Redevance hydraulique (mini hydro exempte ; petite hydro linéaire)
    c. Label Naturemade et TÜV
    d. Programme national “EnergieSuisse après 2010” : subvention pour étude de faisabilité
    e. Le centime paysager pour la conservation des paysages naturels283 (pas en faveur de la mini et petite hydro ; en ce moment dans le paquet de la redevance hydraulique au parlement)
    f. Et des instruments à niveau des Cantons (par exemple BE: <300kW: pas de taxe de concession de 0.015 ct/kWh + des prêts sans intérêts)

2. RPC:
    a. Quelle utilisation? *Fort/faible*
    b. Difficulté avec l’application? *Oui/Non -> explications*
    c. Quelles capacités installées de mini et petite hydro profitent le plus de la RPC ?
    d. Est-ce que les couvercles devraient être éliminés ? *Oui/Non*

3. Le pompage-turbinage avec de la mini et petite hydro:
    a. Potentiel ?
        - Avec eau de surface (aussi combiné avec la protection contre les crues, le stockage d’eau pour les périodes sèches)
        - Avec infrastructures à buts multiples :
            - Eau potable
            - Enneigement artificiel
        - Avec des galeries de vidange désaffectées autour de grands barrages
        - Pour réguler le réseau électrique
    b. Financement : adapter la RPC (avec de l’énergie verte certifiée pour le pompage) ? Paiement de capacité ? Autres ?
    c. Régulation technique : avoir la possibilité de débit résiduel dynamique pour mieux s’adapter aux demande de pointe et avoir plus de flexibilité dans l’opération d’ouvrage avec du stockage ? *Oui/Non –> explications*

[283] http://www.parlament.ch/D/Suche/Seiten/geschaefte.aspx?gesch_id=20083699 (16.10.2009)

4. Label de qualité (label sur la production):
    a. Introduire des standards techniques minimaux pour assurer une certaine qualité? *Oui/Non*
    b. Y lier avec la RPC ou la demande de concession ?

5. Crédits CO_2:
    a. Est-ce que la mini et petite hydro devraient pouvoir générer des Certificats Verts (Tradable Green Certificates) ? *Oui/Non*
    b. Ou est-ce que la RPC devrait être financée en partie à travers une taxe CO_2 ?

6. Réduire les frais de procédures (coûts de transaction):
    a. Quelles procédures peuvent être simplifiées pour la mini et petite hydro (procédures administratives, procédures de demande d'autorisation, procédures RPC) ?
    b. Quelles procédures ne doivent pas être les mêmes pour la mini et petite hydro comparé à la grande hydro ?

Questions ouvertes

7. Quels sont les instruments prioritaires ? Pourquoi? Auriez-vous dit la même chose il y a 5 ans ?

8. Avez-vous des idées pour des nouveaux instruments institutionnels au sein de votre organisation ? Si oui, quelle est leur description ?

9. Quels instruments institutionnels pourraient être liés ensemble ?

10. Quels instruments institutionnels ont besoin d'être adaptés ?

11. Où est-ce que la technologie doit-elle évoluer ? (innovation technologique)

B. Interview questions – Canton of Valais

La promotion de la petite hydro en Valais :

le développement de centrales d'accumulation et à pompage-turbinage

Questions pour l'interview avec XX, xx.xx.xxxx à X

Questions structurées

1. Des centrales petite hydro (<10 MW) d'accumulation et à pompage-turbinage:
   a. Y-a-t-il un potentiel technique, tant pour des centrales petite hydro d'accumulation[284], que tant pour des centrales petite hydro à pompage-turbinage[285] :
      - En utilisant des centrales petite hydro existantes ou prévu ? *Oui/Non –> exemples, évaluation*
      - Avec des lacs en altitude par encore exploités ? *Oui/Non –> exemples, évaluation*
      - Avec des lacs artificiels à construire pour des activités des loisirs ? *Oui/Non –> exemples, évaluation*
      - Avec des infrastructures d'eau potable (existantes ou à construire/agrandir ; par exemple avec surplus des sources) ? *Oui/Non –> exemples, évaluation*
      - Avec des infrastructures d'enneigement (existantes ou à construire) ? *Oui/Non –> exemples, évaluation*
      - Avec des galléries qui ne sont plus exploitées ? *Oui/Non –> exemples, évaluation*
      - Avec des galléries d'amenée dont une chute n'est pas exploitée ? *Oui/Non –> exemples, évaluation*
      - Avec des infrastructures militaires qui ne sont plus utilisées (bunkers, galléries en altitude) ? *Oui/Non –> exemples, évaluation*
      - Autres ? *Oui/Non –> exemples, évaluation*

      Supplément : avez-vous des exemples concrets qui pourrait être utilise comme étude de cas en Valais ?

   b. Quel devrait être le minimum de puissance de production ?
   c. Comment financer l'accumulation et le pompage-turbinage petite hydro :
      1. Adapter la RPC (prime pour énergie de pointe) ? *Oui/Non*
      2. Trading avec le Spot Market ? *Oui/Non*
         - Avoir un minimum de puissance ? Si oui, combien ?
      3. Rémunération à travers des contrats de services auxiliaires décentralisés (régulation du réseau électrique, réserve de production et consommation si pompage, power balancing) ? Oui/Non
         - Avoir un minimum de puissance ? Si oui, combien ?

[284] Ceci inclut aussi les centrales d'accumulation avec pompes d'alimentation.
[285] Ceci inclut aussi les centrales à pompage-turbinage pur.

4. Les sources de production stochastiques doivent avoir des capacités de contrôler leur production et donc doivent inclure dans leur système des capacités de stockage d'énergie, telles que des centrales petite hydro à pompage-turbinage ? Oui/Non

- Petite hydro en général : Est-ce que la petite hydro en général devrait pouvoir produire des crédits CO_2 pour compenser des centrales thermiques ? *Oui/Non*

d. Faut-il avoir la possibilité de débit résiduel dynamique pour mieux s'adapter aux demandes de pointe et avoir plus de flexibilité dans l'opération de centrales d'accumulation et à pompage-turbinage? *Oui/Non –> explications*

e. De manière générale, est-ce que l'accumulation et le pompage-turbinage petite hydro devrait être pris en compte dans le cadre institutionnel ? *Oui/Non –> explications*

2. Réduire les coûts administratifs (coûts de transaction) pour la petite hydro en général:

a. Quelles procédures administratives peuvent être simplifiées pour la petite hydro par rapport à la grande hydro :

1. En général ? *Description*
2. Et spécifiquement en cas de réhabilitation ? *Description*
3. Et spécifiquement au sein d'infrastructure existantes ? *Description*

b. Est-ce que des « checklists » pour chaque procédure pourraient être utiles ? Si oui, lesquels en priorité ?

c. Quelles autres simplifications pourraient être faites ?

d. Facultatif : Pouvez-vous donner une estimation sur les coûts et les durées pour chaque point dans la « Procédure à suivre pour la construction d'une petite centrale hydraulique » ? (voir annexe)

3. Label de qualité / Standardisation technique:

a. Comment garantissez-vous la qualité de conception et de construction de vos ouvrages ? *Description*

b. Faut-il introduire des standards techniques minimaux pour assurer une certaine qualité (label de qualité)? *Oui/Non –> explications*

1. Si oui, faut-il avoir des standards par composantes (p.ex. efficience de la turbine) ou sur l'ouvrage dans son ensemble (p.ex. efficience globale de l'ouvrage) ?
    - Si par composantes, lesquelles ?
2. Si oui, y lier avec la RPC ou la demande de concession ?

c. Faut-il plus de standardisation technique ? *Oui/Non –> explications*

1. Si oui, sur quelles composantes ?

Questions ouvertes

4. Avez-vous des idées pour des nouveaux instruments institutionnels[286] (ou modifications d'instruments existants) au sein de votre organisation pour la promotion de la mini (<1 MW) et petite (<10 MW) hydro en Valais ? Si oui, quelle est leur description ?

5. Où est-ce que la technologie doit-elle évoluer ? (innovation technologique)

Divers

6. Quel est l'impact sur la production hydroélectrique de la régulation des débits résiduels lors de la renégociation des concessions ?

7. Tout autre commentaire :

8. Seriez-vous d'accord de participer à une séance de synthèse et de consolidation des résultats de cette recherche empirique ?

Annexe : - Résumé de la thèse

- ***Diagramme des procédures dans le Canton du Valais***
- ***Réductions des coûts administratifs : commentaire***

[286] Un instrument institutionnel est un moyen à travers les institutions pour atteindre des objectifs ; les institutions étant les « règles du jeu » selon North (1990) et non pas les acteurs. Quelques exemples dans le cas de la promotion de la petite hydro en Suisse :

- La RPC : promotion financière et droit Suisse (régulation publique)
- Label « Naturemade » : promotion financière et initiative privée
- EnergieSuisse : programme du gouvernement d'information, sensibilisation et de soutien financier pour des études de faisabilité

C. Survey questions

Questions 6 and 7 added by the author.

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Feed-in Tariff and Economic Profit of Small Hydropower Plants in Switzerland

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(05-914-726)

March 2011

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A.1.3. Survey

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK
Bundesamt für Energie BFE
Sektion Wasserkraft

cepe
Centre for Energy Policy and Economics
Department of Management, Technology and Economics

Erhebung von Betriebsdaten von Kleinwasserkraftwerken die von der Kostendeckenden Einspeisevergütung (KEV) profitieren

1. Identifikation der Anlage			
Name der Anlage:	______		
Unternehmung / Betreiber:	______		
Adresse der Anlage, ansonsten des Besitzers:	Strasse, Nummer: ______ PLZ, Ort: ______		
Koordinaten der Anlage:	x: ______	y: ______	
Kote des Maschienensaalbodens:	______ m.ü.M.		
Kote der Fassung:	______ m.ü.M.		
Projekttyp gemäss KEV Anmeldung:	☐ Wiederinbetriebsetzung/Reaktivierung stillgelegter Anlage ☐ Elektrifizierung einer vormals rein mechanischen Kraftübertragung ☐ Erweiterung (Ausbauwassermenge und/oder Fallhöhe) ☐ Erneuerung (Wirkungsgradverbesserung) ☐ Gesamterneuerung ☐ Neubau an bisher energetisch ungenutzem Standort ☐ andere: ______		
Inbetriebnahmedatum:	______	**Datum der Ausser-betriebsetzung:**	______
Bemerkung:			

1

2. Allgemeine Angaben

Produzierte Strommenge:			**Effektive Vergütung (KEV) :**	
Jahr 2007	________	kWh	________	ct./kWh
Jahr 2008	________	kWh	________	ct./kWh
Jahr 2009	________	kWh	________	ct./kWh
Jahr 2010	________	kWh	bis Datum: ____ ____	ct./kWh

Prozentuale Jahresverteilung Stromproduktion:	Sommer (April-Sept.): ______	%	Winter (Okt.-März): ______	%	
Brutto-Fallhöhe:	________	m			
Ausbauwassermenge:	________	Liter/Sekunde			
Ausbaugrad:	________	Anzal Tage pro Jahr an denen die Ausbauwassermenge erreicht oder überschritten wird.			
Restwassermenge:	________	Liter/Sekunde			
Mittlere mechanische Bruttoleistung:	________	kW			
Inst. Turbinenleistung:	________	kW			
Max. Leistung ab Generator:	________	kWel			

Anlagentyp:

- ☐ Durchlaufkraftwerk
- ☐ Ausleitkraftwerk
- ☐ Trinkwasserkraftwerk
- ☐ Pumpspeicherkraftwerk
- ☐ Abwasserkraftwerk
- ☐ Dotierwasserkraftwerk
- ☐ andere: ________

Turbinentyp:	☐ Pelton ☐ Kaplan ☐ Francis	☐ Ossberger ☐ andere: ______________
Wassernutzungsrecht:	☐ Konzession ☐ Verfügungsrecht ☐ Ehehaftes Recht	☐ Bewilligung ☐ Andere Rechtsgrundlage: ______________
• Ablaufdatum Wassernutzungsrecht: ______________		
Bemerkung:		

3. Finanzierung der Anlage und Investitionskosten

Gesamtinvestition für das Projekt: ________	SFr.	
• Abweichung von der geplanten Gesamtinvestition: ________	%	
Finanzierung durch Eigenkapital: ________	SFr.	
Finanzierung durch Fremdkapital: ________	SFr.	**Durchschnittlicher Zinssatz Fremdkapital:** ____ %
• davon weitere Subventionsbeiträge (z.B. zinslose Darlehen): ________	SFr.	

Aufteilung der Investitionen (Das Total aus (1)-(3) entspricht den Gesamtinvestitionskosten)

			Abweichung von geplanten Kosten in %:
(1) Investitionen Wasserbau[1]:	________	SFr.	________ %
(2) Investitionen Elektromechanik[2]:	________	SFr.	________ %
(3) Restliche Investition:	________	SFr.	________ %
• davon Kosten der Massnahmen zum Schutz der Umwelt:	________	SFr.	________ %

Bemerkung:

[1] Investitionskosten für alle wasserbaulichen Elemente inklusive Druckleitung + einem pauschalen Anteil an Planungs- und Bauleitungskosten. Dieser Anteil darf nicht mehr sein als 15% der Kosten der wasserbaulichen Elemente. Siehe Richtlinie zu Anhang 1.1 der Energieverordnung (EnV) (Anschlussbedingungen für Kleinwasserkraft) Ziff. 3.4

[2] Investitionen für alle elektromechanischen Elemente (z.B. Turbinen, Pumpen, Generatoren, Transformator, Schaltanlage)

4. Durchschnittliche Betriebs- und Unterhaltskosten				
Die unten angegebenen Kennzahlen beziehen sich auf den durchschnittlichen Wert folgender Jahre[3]:	2007 ☐	2008 ☐	2009 ☐	2010 ☐
Betriebs- und Unterhaltskosten (Total aus (1)-(6)):	______ SFr./Jahr			
• (1) Wasserzinse:	______ SFr./Jahr			
• (2) Personalkosten:	______ SFr./Jahr			
• (3) Energiekosten:	______ SFr./Jahr			
• (4) Materialkosten:	______ SFr./Jahr			
• (5) Fremdleistungen:	______ SFr./Jahr			
• (6) Sonstige Kosten:	______ SFr./Jahr			
Abschreibungen:	______ SFr./Jahr			
Versicherungskosten:	______ SFr./Jahr			
Steuern:	______ SFr./Jahr			
Bemerkung:				

[3] Falls in diesem Jahr ausserordentliche Aufwendungen getätigt wurden, bitten wir Sie dies bei Bemerkungen festzuhalten.

5. Standortfaktoren

Distanzen:

- nächster Strassenanschluss: ______________ km
- nächste grössere Siedlung: (>1000 Einwohner) ______________ km
- nächstes Wasserkraftwerk (< 10MW): ______________ km
- nächstes Wasserkraftwerk (> 10MW): ______________ km

Geologie des Baugrundes:	sehr einfach ☐	einfach ☐	mittel ☐	schwer ☐	sehr schwer ☐
Zugänglichkeit:	sehr einfach ☐	einfach ☐	mittel ☐	schwer ☐	sehr schwer ☐

Raumzone: (nur bei zutreffenden ankreuzen)

☐ Grundwasserschutzzone
☐ Gewässerschutzzone
☐ Naturschutzgebiete

Bemerkung:

6. Meinungsfragen und Kommentar

Allgemeine Meinung zur KEV und Verbesserungsvorschläge:

Gibt es Ihrer Meinung nach weitere Möglichkeiten den Bau von Kleinwasserkraftwerken zu erleichtern? (z.B. Vereinfachung Bewilligungsverfahren, Konzessionsvergabe, etc.)

7. Zusatzfragen[4]:

Sollte die Spitzenstromproduktion mit zusätzlichen Anreizen gefördert werden? (z.B. durch Zahlung einer Prämie)?

☐ Ja ☐ Nein ☐ Ich weiss nicht

Ein grosses Problem des heutigen KEV Systems ist die Qualitätssicherung der Planung und des Baus von Anlagen. Soll ein Qualitätslabel eingeführt werden?

☐ Ja ☐ Nein ☐ Ich weiss nicht

wenn ja,

sollte das Qualitätslabel generelle Kriterien für die gesamte Anlage (z.B. Effizienz der Anlage) oder Kriterien zu einzelnen Teilen (z.B. Turbine) beinhalten?

☐ generelle Kriterien ☐ spezifische Kriterien zu einzelnen Teilen ☐ Ich weiss nicht

sollte man das Qualitätslabel mit der KEV oder mit der Konzessionsvergabe verbinden?

☐ mit KEV ☐ mit Konzessionsvergabe ☐ Ich weiss nicht

wenn nein,

sollten gewisse Teile der Anlage weiter standardisiert werden?

☐ Ja ☐ Nein ☐ Ich weiss nicht

wenn ja, welche Teile?

____

____

____

____

[4] Zusatzfragen müssen nicht zwingend beantwortet werden. Wir wären Ihnen jedoch sehr dankbar, wenn Sie sich auch für diese Fragen kurz Zeit nehmen, da sie für weitere Auswertungen hilfreich sind.

Sollte die Pump-Speicher-Anwendung bei Kleinwasserkraftwerken in der Förderung der Erneuerbaren Energien einbezogen werden? ☐ Ja ☐ Nein			
Vergrösserung Speichervolumen:	Ist eine Vergrösserung des Speichervolumens denkbar?	☐ Ja	☐ Nein
	Wenn ja, auf welche Grösse?:	____________	m^3
Pump-Speicher:	Ist eine Pump-Speicher-Anwendung bei Ihrer Anlage denkbar?	☐ Ja	☐ Nein
	Wenn ja, wie gross wäre der Speicher des unteren Reservoirs?	____________	m^3
Falls Trinkwasser-kraftwerk:	Wurde die Kapazität zusätzlicher wasserbaulicher Elemente angepasst? (z.B. Leitungen, Reservoir)	☐ Ja	☐ Nein
Bemerkung:			

Dieser Fragebogen wurde wahrheitsgetreu ausgefüllt von (Name, Vorname)____________________

Telefonnummer für weitere Auskünfte: ____________________

Ort und Datum ____________________

Unterschrift ____________________

D. Survey results

Source: (Manser, 2011)

A.4. Evaluation of Qualitative Answers

Questions Part 6 and 7:

6.1. What is your general opinion on the current KEV model and are there possibilities for an improvement?

6.2. Are there any possibilities to further facilitate the construction of SHPPs (e.g. simplification of approval procedure, granting of the concession, etc.)?

7.1. Should the production of peak current be promoted with additional incentives (e.g. by paying a premium)?

7.2. A large problem of the current KEV model is the quality assurance of planning and construction of SHPPs. Would it make sense to introduce a quality label?

7.2a. If yes,
7.2a.1 Should the label include either general criteria concerning the complete power plant (e.g. concerning efficiency of the plant) or should it include criteria for specific elements of the power plant (e.g. turbine)?
7.2a.2 Should the quality label be combined with the granting of the KEV tariff or with the granting of the concession?

7.2b. If no,
7.2b.1 Are there elements of SHPPs that should be further standardized?
7.2b.2 If yes, which elements?

7.3. Should there be an additional promotion of pumped storage SHPPs?

7.4a. Would an increase in the storage volume be possible?

7.4b To what volume could the storage be increased?

7.5a. Would the usage of pumped storage be possible?

7.5b. What would be the volume of the lower reservoir?

7.6. For DWPP: Was the capacity of additional hydraulic constructions (e.g. pressure pipes, reservoir) adjusted?

Evaluation:

6.1. and 6.2.:

These two questions were answered similarly. In the following a collection of the main answers (sorted from highest to lowest frequency.)

a. General simplification or shortening of approval procedure and granting of concession
b. Help with or regulation of opposition
c. Faster payments by Energiepool Schweiz
d. Simplification or shortening of approval procedure and granting of concession for small SHPPs
e. Clear deadlines from swissgrid to increase planning security
f. Change of KEV application deadlines
g. Fix KEV tariff (independent of production)
h. Increased cooperation between cantons and federation
i. Elaboration of cantonal water strategy
j. Load profile measurement is too expensive
k. Increased remuneration for small SHPPs
l. Do not promote larger SHPPs (>2MW)
m. Contradiction: 25 years of remuneration but only for example 20 years validity of concession.

Tab. 32: Evaluation of qualitative questions from part 7 of the survey

Question		ALL	100-300kW	300-1'000kW	1-3MW	3-10MW	DCPP	DWPP	ROPP	Large Company[11]	Small Company
Total		**166**	**22**	**25**	**10**	**5**	**32**	**76**	**52**	**23**	**143**
	Yes	62	6	12	5	1	10	27	21	6	56
7.1.	**Total**	**137**	**20**	**23**	**10**	**2**	**28**	**61**	**43**	**22**	**115**
	Percentage	45.3	30.0	52.2	50.0	50.0	35.7	44.3	48.8	27.3	48.7
	Yes	34	4	5	3	0	8	20	6	5	29
7.2.	**Total**	**144**	**19**	**24**	**9**	**3**	**27**	**65**	**48**	**22**	**122**
	Percentage	23.6	21.1	20.8	33.3	0.0	29.6	30.8	12.5	22.7	23.8
	General Criteria	25	4	3	3	0	5	15	5	5	20
7.2a.1	**Total**	**30**	**4**	**3**	**3**	**0**	**7**	**17**	**6**	**5**	**25**
	Percentage	83.3	100.0	100.0	100.0	-	71.4	88.2	83.3	100.0	80.0
	With KEV	28	3	4	2	0	7	17	4	5	23
7.2a.2	**Total**	**35**	**4**	**4**	**3**	**0**	**10**	**19**	**6**	**5**	**30**
	Percentage	80.0	75.0	100.0	66.7	-	70.0	89.5	66.7	100.0	76.7
	Yes	17	1	3	1	1	5	9	2	2	15
7.2b.1	**Total**	**106**	**14**	**19**	**7**	**3**	**18**	**48**	**37**	**16**	**90**
	Percentage	16.0	7.1	15.8	14.3	33.3	27.8	18.8	5.4	12.5	16.7
	Yes	49	6	10	4	2	13	15	19	8	41
7.3	**Total**	**125**	**19**	**21**	**9**	**4**	**27**	**50**	**44**	**21**	**104**
	Percentage	39.2	31.6	47.6	44.4	50.0	48.1	30.0	43.2	38.1	39.4
	Yes	9	1	2	1	0	2	0	7	1	8
7.4a.	**Total**	128	20	22	9	4	26	53	43	18	110
	Percentage	7.0	5.0	9.1	11.1	0.0	7.7	0.0	16.3	5.6	7.3
	Yes	4	3	0	0	0	1	1	2	1	3
7.5a.	**Total**	**132**	**20**	**25**	**8**	**4**	**28**	**56**	**42**	**18**	**114**
	Percentage	3.0	15.0	0.0	0.0	0.0	3.6	1.8	4.8	5.6	2.6
	Yes	46	7	4	0	0	1	41	4	6	40
7.6.	**Total**	**82**	**13**	**10**	**0**	**1**	**4**	**68**	**10**	**11**	**71**
	Percentage	56.1	53.8	40.0	-	0.0	25.0	60.3	40.0	54.5	56.3

Answers 7.2b.2:

Most SHPP operators have the opinion that standardization does not make sense as most plants are constructed according to site-specific environmental factors. However, some consider it helpful to standardize micro hydropower (especially the turbine). Others conclude that standardization will lead to losses in efficiency. Elements mentioned are: fish ladder, alternator, rake, control system for reserved flow.

Answers 7.4b.:

Only 4 SHPPs listed a resulting volume (between 500 and 15'000m^3).

Answers 7.5b.:

Only 3 SHPPs listed a resulting volume (between 1'200 and 400'000m^3).

[11] All SHPPs owned by larger power supply companies were considered as 'large company'.

E. Overview of the papers on the coherence framework

Table 1: Overview of publications on the coherence framework

Table 2: Overview of working and conference papers on the coherence framework

Table 3: Overview of working and conference papers on the recent development of the coherence framework

Table 1: Overview of publications on the coherence framework

Authors and Date	**(Finger, Groenewegen et al., 2005)**	**(Künneke and Finger, 2007)**	**(Künneke, 2008)**	**(Ménard, 2009)**	**(Künneke, Groenewegen et al., 2010)**
Title of the paper	The quest for coherence between institutions and technologies in infrastructures	Technology matters: the cases of the liberalization of electricity and railways	Institutional reform and technological practice: the case of electricity	From technical integrity to institutional coherence: regulatory challenges in the water sector	Aligning modes of organization with technology: Critical transactions in the reform of infrastructures
Topics / Keywords	Network industries, liberalisation, technological change, governance	Regulation, liberalisation, technological change, critical functions	Technological and institutional change, technological paradigm and trajectories	Critical infrastructures, core transactions, micro-institutions	Modes of organisation, reforms in infrastructures, institutional change
Network industries	Electricity, air transport	Electricity, railways	Electricity	Water	Network industries
Time scale	Since liberalisation	Since liberalisation	Since the 1970s	Since the 1980s	Since the 1980s
Coherence definition	*"Coherence is defined in terms of the similarity of coordination mechanisms and the scope of control"*	*"There is a necessity for some coherence between institutions and technology in order to support the satisfactory functioning of the system. In other words, institutional arrangements need to be in line with the technical needs of infrastructures in order to secure the technical reliability of the system."*	-	-	-
Take away messages for the coherence framework development	- *"The degree of coherence determines the performance of infrastructures."* - *"Institutional change needs to support technological change."* - *"Technological change can be needed so as to support institutional change."*	- *"It is argued that there is a necessity to align technological and institutional regimes into a coherent framework in order for the technical systems to function reliably and sustainably."* - *"Under the conditions of a liberalized market, the question arises whether there are appropriate regulatory instruments*	- *"There is a need for coherence between institutions and technological practice, so as to safeguard the satisfactory functioning of electricity infrastructure. The identification of possible incoherences allows for a better understanding of the potential drivers for change and the evolutionary processes*	- *"Guaranteeing coherence between core transactions and technical functions."*	- *"Our analysis suggests that what is crucial is the capacity to align reforms in modes of organizations with critical transactions in order to preserve a coherent framework in which critical technical control functions are related to a specific set of modes of organization so as to guarantee reliable*

	to create a suitable institutional framework that re-aligns the critical institutional arrangements with the critical technical functions."	*of which they may be part."* - *"The causal relations between technological and institutional changes should be formalized more clearly."*		*system services."* - Within co-evolution the technological functioning of network industries has to be in line with appropriate modes of organisation.[1]

[1] Williamson (1996: 12) stated that in competitive environments, the market forces push decision-makers towards adopting modes of organisation aligned with the characteristics of the transactions they support, whilst reducing as much as possible the inevitable contractual hazards. If the modes of organisation are imposed on the industry by a regulator, the latter needs to have certain knowledge of the transactions taking place. However, transaction costs economics, which lays at the ground of this approach, has not really integrated the technological perspective (Künneke, Groenewegen et al., 2010). Research with the coherence framework integrates the technological perspective.

Sources: in the table

Table 2: Overview of working and conference papers on the coherence framework

Authors and Date	**(Groenewegen, 2005)**	**(Scholten, 2009)**	**(Scholten, 2009a)**	**(Crettenand, 2009)**	**(Scholten, 2009b)**	**(Bolton and Foxon, 2010)**
Title of the paper	Designing markets in infrastructures: from blueprint to learning	The role of coherence in the coevolution between institutions and technologies	Matching institutions to technologies: the case of a transition to hydrogen in the Netherlands	Coherence between institutions and technologies - The case of mini hydropower in Switzerland	Pursuing the alignment of institutions to technologies as a policy objective in times of technical change	Governing infrastructure networks for a low carbon economy: the case of the smart grid in the UK
Topics / Keywords	Static blueprint of private-public ordering, dynamic layer model of technological and socio-economic systems	Coherence, co-evolution, institutions, technologies	Coherence, institutions, technologies	Institutional frameworks, regulation	Coevolution, institutions, technological change, alignement	Co-evolution, socio-technical transitions, smart grid
Network industries	-	-	Specific case of Hydrogen	Specific case of mini hydropower	-	Electricity
Time scale	-	-	2000-2050	Since liberalisation	-	-
Coherence definition	-	Finger et al. (2005)	*"the concept of coherence as a means to compare institutions and technologies"*	Finger et al. (2005)	Finger et al. (2005)	-
Take away messages for the coherence framework development	- *"The domains of technology, economics and institutions co-evolve over time."* - *"The static blueprint economic perspective provides basic insights into the design of economizing institutional arrangements, but hopelessly fails in the case of designing markets in infrastructures."* - Dynamics (i.e. co-evolution) and the role of actors have to be taken into account.	- Keep only 4 modes of organisation (see (Künneke, Groenewegen et al., 2010)). - Difficulty to measure coherence.	- Coherence as a mean of policy design.	- Coherence at several level, i.e. electricity sector and specific production technology levels. - More research needed on the dynamics.	- Coherence to compare institutions and technologies. - Coherence as alignment design principle.	- *"It is argued that changes are required to the formal and informal institutions which govern the sector in order to promote a more coherent relationship between technological and institutional change, leading to a productive innovation system which allows firms to collaborate across the electricity value chain and develop inter-firm/cross sector innovation partnerships."*

Sources: in the table

Table 3: Overview of working and conference papers on the recent development of the coherence framework

Authors and Date	**(Duthaler and Finger, 2010)**	**(Finger, Laperrouza et al., 2010)**	**(Crettenand, Laperrouza et al., 2010)**	**(Asquer, 2011)**	**(Crettenand, 2011a)**
Title of the paper	The Missing Link between Coherence and Performance in Network Industries	Governing the dynamics of network industries	Performance and Coherence in Network Industries	Aligning Technological and Institutional Change: Maritime Transport in West Mediterranean Sea	Pump-storage small hydropower as an example of co-evolution between institutions and technologies
Topics / Keywords	Coherence, network constraints, performance	Coevolution, dynamics, governance	Performance, coherence, institutions	Coherence, ports, actors	Co-evolution, coherence, institutional frameworks, small hydropower
Network industries	Electricity, air traffic	-	Electricity, railways, air traffic	Maritime transport	Electricity
Time scale	Since liberalisation	Since liberalisation	Since liberalisation	1990-2000	Since liberalisation
Coherence definition	Finger et al. (2005)	Finger et al. (2005)	Finger et al. (2005)	Finger et al. (2005)	Finger et al. (2005)
Take away messages for the coherence framework development	- Introduction of the network constraints (the network function exists because of the constraints). - The influence of coherence on performance is time- and sector-specific.	- Introduction of the different sets of configuration of network industries: each of the three configurations is coherent between the state of the technology and the way the critical technical functions are governed. - *"All actors behave strategically vis-à-vis one another and the dynamics are precisely the result of all these strategic behaviors combined."*	- Performance has to be firstly defined, before aligning institutions and technologies. - Identification of the weaknesses of the framework.	- Perception of the actors matters more than acknowledge so far in the framework. - Need to formulate testable hypothesis about the links between technological and institutional factors, coherence and performance.	- More coherence needed within the facilitation of RETs, i.e. not solely focus on quantity of renewable kWh, but also on the alignment between demand and supply. - The 4 coherence perspectives applied to distributed energy storage and flexible production. - Coherence has also to be ensured within institutions themselves. - Align institutional and technological changes within a co-evolutionary process.

Sources: in the table

F. Cantonal legislation

Source: (Zysset, Pfammatter et al., 2007)

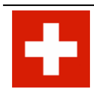
3.1.3 Aufbau und Organisation der kantonalen Gesetzgebungen

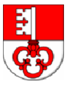
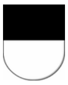
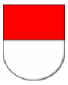
Die kantonale wasserwirtschaftliche Gesetzgebung orientiert sich bei der Organisation und dem Aufbau der Vollzugsregelungen weitgehend an den bundesrechtlichen Vorgaben. Die meisten Kantone organisieren sich rechtlich sektoral und kennen ein Gewässerschutzgesetz, ein Wasserrechtsgesetz und ein Wasserbaugesetz. Die Fischereiwirtschaft als staatliches Monopol wird üblicherweise in einem separaten Gesetzestext geregelt. Ebenfalls eigene rechtliche Grundlagen erstellen die Kantone für die Schifffahrt.

Häufig (immerhin 8 Kantone) ist auch, dass die Vollzugsbestimmungen zu den Bereichen Wassernutzung und Hochwasserschutz in einem gemeinsamen Gesetzestext zusammengefasst werden. Die Kantone Schaffhausen und Zürich sprechen von einem Wasserwirtschaftsgesetz, andere Kantone von einem Wasserrechtsgesetz, Wassergesetz oder einfach Wassernutzungs- und Wasserbaugesetz. Interessant ist auch, dass 2 Kantone (Glarus und Appenzell Innerhoden) ihre Wasserrechtsgesetzgebung im Einführungsgesetz zum schweizerischen Zivilgesetzbuch festgehalten haben, wobei der Kanton Glarus momentan ein kantonales Gesetz für Wasserrecht und Wasserbau erarbeitet.

Ein eigentliches "Wassergesetz" kennen die Kantone Solothurn ("Wasserrechtsgesetz"), Zug ("Gesetz über die Gewässer") und Genf ("*Loi sur les eaux*"). Im Kanton Jura ist ein entsprechendes Gesetz in Ausarbeitung. Im Kanton Solothurn ist ein "Gesetz über Wasser, Boden und Abfall" in Vernehmlassung, welches das bestehende Wasserrechtsgesetz ersetzen soll.

Tabelle 2 gibt eine Übersicht über die wichtigsten Gesetze.

Kanton	Gewässerschutz	Wassernutzung	Hochwasserschutz
	Bundes sind im Bundesgesetz über den Schutz der Gewässer (GSchG) vom 24. Januar 1991	Bundesgesetz über die Nutzbarmachung der Wasserkräfte vom 22. Dezember 1916 (WRG)	Die Kompetenzen des Bundes sind im Bundesgesetz über den Wasserbau vom 21. Juni 1991 (WBG)
	Einführungsgesetz zum Gewässerschutzgesetz vom 8. Dezember 1974	Wasserwirtschaftsgesetz vom 2. Juni 1991	Wasserwirtschaftsgesetz vom 2. Juni 1991
	Kantonales Gewässerschutzgesetz vom 11. November 1996	Wassernutzungsgesetz vom 23. November 1997 Wasserversorgungsgesetz vom 11. November 1996	Gesetz über den Gewässerunterhalt und Wasserbau vom 14. Februar 1989
	Einführungsgesetz zum Bundesgesetz über den Schutz der Gewässer vom 27. Januar 1997	Wassernutzungs- und Wasserversorgungsgesetz vom 20. Januar 2003	Wasserbaugesetz vom 30. Januar 1997
	Kantonales Umweltgesetz (KUG) vom 11. März 2007	Gewässernutzungsgesetz vom 16. Februar 1992	Wasserbaugesetz vom 30. November 1980

Kanton	Gewässerschutz	Wassernutzung	Hochwasserschutz
	Kantonale Verordnung zum Bundesgesetz über den Schutz der Gewässer vom 19. April 2000	Wasserrechtsgesetz vom 11. September 1973	Wasserrechtsgesetz vom 11. September 1973
	Vollziehungsverordnung zum Bundesgesetz über den Schutz der Gewässer (kantonale Gewässerschutzverordnung) vom 16. März 2006	Gesetz über den Wasserbau und die Wassernutzung (Wasserbaugesetz) vom 31. Mai 2001	Gesetz über den Wasserbau und die Wassernutzung (Wasserbaugesetz) vom 31. Mai 2001
	Einführungsgesetz zur Bundesgesetzgebung über den Schutz der Gewässer (Kantonales Gewässerschutzgesetz) vom 29. April 1973	Gesetz über die Rechte am Wasser (Wasserrechtsgesetz) vom 30. April 1967	Gesetz über die Rechte am Wasser (Wasserrechtsgesetz) vom 30. April 1967
	Einführungsgesetz zum Bundesgesetz über den Schutz der Gewässer vom 7. Mai 1995	Gesetz über die Einführung des Schweizerischen Zivilgesetzbuches im Kanton Glarus vom 7. Mai 1911	Gesetz über die Einführung des Schweizerischen Zivilgesetzbuches im Kanton Glarus vom 7. Mai 1911
	Gesetz über die Gewässer (GewG) vom 25. November 1999	Gesetz über die Gewässer (GewG) vom 25. November 1999	Gesetz über die Gewässer (GewG) vom 25. November 1999
	Ausführungsgesetz zum BG vom 8. Oktober 1971 über den Schutz der Gewässer gegen Verunreinigung vom 22. Mai 1974	Gesetz über die öffentlichen Sachen vom 4. Februar 1972 Gesetz über das Trinkwasser von 1979	Gesetz über den Wasserbau vom 26. November 1975
	Gesetz über die Rechte am Wasser (Wasserrechtsgesetz) vom 27. September 1959	Gesetz über die Rechte am Wasser (Wasserrechtsgesetz) vom 27. September 1959 Gesetz betreffend Vollzug des Bundesgesetzes über die Nutzbarmachung der Wasserkräfte vom 29. März 1925	Gesetz über die Rechte am Wasser (Wasserrechtsgesetz) vom 27. September 1959*
	Kantonale Gewässerschutzverordnung vom 12. Dezember 2000	Gesetz betreffend Einführung des Bundesgesetzes über Nutzbarmachung der Wasserkräfte vom 10. Januar 1918 Gesetz über die Nutzung von öffentlichem Fluss- und Grundwasser IWB-Gesetz vom 1. Mai 2004	
	Gesetz über den Gewässerschutz vom 1. Januar 2005	Gesetz über die Wasserversorgung der basellandschaftlichen Gemeinden vom 3. April 1967 Gesetz über den Wasserbau und die Nutzung von Gewässer vom 1. Januar 2005	Gesetz über den Wasserbau und die Nutzung von Gewässer vom 1. Januar 2005
	Einführungsgesetz zum Gewässerschutzgesetz vom 27. August 2001	Wasserwirtschaftsgesetz vom 18. Mai 1998	Wasserwirtschaftsgesetz vom 18. Mai 1998
	Gesetz über die Einführung der Bundesgesetze über den Umweltschutz und den Schutz der Gewässer vom 16. Februar 2004	Gesetz über den Wasserbau und die Wassernutzung vom 25. September 2006	Gesetz über den Wasserbau und die Wassernutzung vom 25. September 2006
	Einführungsgesetz zum BG über den Schutz der Gewässer vom 25. April 1993	Einführungsgesetz zum Schweizerischen Zivilgesetzbuch vom 30. April 1911	Wasserbaugesetz vom 29. April 2001
	Vollzugsgesetzgebung zur eidgenössischen Gewässerschutzgesetzgebung vom 11. April 1996	Gesetz über die Gewässernutzung vom 5. Dezember 1960	Wasserbaugesetz vom 23. März 1969

Kanton	Gewässerschutz	Wassernutzung	Hochwasserschutz
	Einführungsgesetz zum Bundesgesetz über den Schutz der Gewässer (Kantonales Gewässerschutzgesetz) vom 8. Juni 1997	Wasserrechtsgesetz des Kantons Graubünden vom 12. März 1995	Gesetz über Bewuhrung und Verbauung der Flüsse und Wildbäche vom 7. März 1870
	Einführungsgesetz zum eidgenössischen Gewässerschutzgesetz vom 11. Januar 1977 Gesetz über die Nutzung und den Schutz der öffentlichen Gewässer vom 22. März 1954	Gesetz über die Nutzung und den Schutz der öffentlichen Gewässer vom 22. März 1954 Gesetz über die Benutzung der Gewässer zur Betreibung von Wasserkraftwerken vom 28. Februar 1856	Gesetz über Raumplanung, Umweltschutz und Bauwesen vom 19. Januar 1993
	Einführungsgesetz zum Bundesgesetz über den Schutz der Gewässer vom 24. Januar 1991	Wassernutzungsgesetz vom 25. August 1999	Gesetz über den Wasserbau vom 25. April 1983
	Legge d'applicazione della legge federale contro l'inquinamento delle acque dell' 8 Ottobre 1971 Decreto esecutivo che designa il dipartimento e il servizio competenti in materia di protezione delle acque dell' inquinamento (del 3 settembre 1991)	Legge sull'utilizzazione delle acque (del 7 ottobre 2002) Regolamento sull'utilizzazione delle acque (del 29 aprile 2003)	Legge cantonale sui territori soggetti a pericoli naturali (del 29 gennaio 1990)
	Loi sur la protection des eaux contre la pollution (LPEP) du 17 septembre 1974 Loi sur le marchepied le long des lacs et sur les plans riverains (LML) du 10 mai 1926	Loi sur l'utilisation des lacs et cours d'eau dépendant du domaine public (LLC) du 5 septembre 1944 Loi sur la distribution de l'eau du 30 novembre 1964 Loi réglant l'occupation et l'exploitation des eaux souterraines dépendant du domaine public cantonal (LESDP) du 12 mai 1948	Loi sur la police des eaux dépendant du domain public (LPDP) du 3 décembre 1957
	Gesetz betreffend die Vollziehung des BG über den Schutz der Gewässer gegen die Verunreinigung vom 16. November 1987	Gesetz über die Nutzbarmachung der Wasserkräfte vom 28. März 1990	Gesetz über die Wasserläufe vom 6. Juli 1932; Anstehendes Gesetz: Gesetz über den Wasserbau vom 15. März 2007
	Loi sur la protection des eaux de 15 octobre 1984	Loi sur les eaux du 24 mars 1953	Loi sur les eaux du 24 mars 1953
	Loi sur les eaux du 5 juillet 1961 (dernière mise à jour: 2004) Loi sur l'organisation des Services industriels de Genève du 5 octobre 1973	Loi sur les eaux du 5 juillet 1961 (dernière mise à jour: 2004) Loi sur l'organisation des Services industriels de Genève du 5 octobre 1973	Loi sur les eaux du 5 juillet 1961 (dernière mise à jour: 2004)
	Loi sur l'utilisation des eaux du 26 octobre 1978	Loi sur l'utilisation des eaux du 26 octobre 1978 Loi concernant l'entretien et la correction des eaux du 26 octobre 1978 Loi portant introduction de la loi fédérale du 9 octobre 1992 sur les denrées alimentaires et les objets usuels	Loi sur la construction et l'entretien des routes du 26 octobre 1978 Loi concernant l'entretien et la correction des eaux du 26 octobre 1978

Tabelle 2: Übersicht über die wichtigsten kantonalen wasserwirtschaftlichen Gesetzgebungen (Stand: August 2007)

G. Swiss definitions for storage and pumped-storage hydropower

Table: Swiss definitions for storage and pumped-storage hydropower

Type	Description	French name	German name
Storage plant	Hydropower plant with storage capacity (only natural inflows)	Centrale d'accumulation	Speicherkraftwerk
Storage plant with auxiliary pump	Storage plant filled by natural inflows and pumped inflows from lower reservoir (turbined water does not go back in this reservoir)	Centrale d'accumulation avec pompes d'alimentation	Speicherkraftwerk mit Zubringerpumpe
Pumped-storage plant	Hydropower plant with connected upper and lower reservoir (only natural inflows); can produce electricity in turbine mode or store water in pump mode.	Centrale à pompage-turbinage	Pumpspeicher-kraftwerk
Pure pumped-storage plant	Pumped-storage plant operating as a closed system, therefore no inflows and outflows from the system.	Centrale à pompage-turbinage pur	Umwälzwerk

Source: BFE, 2010

H. Swiss storage and pumped-storage SHP plants in 2010

Table: Storage and pumped-storage SHP plants in Switzerland in 2010

Type	Name of the plant	Location	Canton	Maximal installed capacity at the generator [MW]
Pumped-storage	Bortelalp	Ried-Brig	VS	2.35
	Engeweiher	Schaffhausen	SH	5.00
	Oberems (Argessa)	Oberems	VS	7.30
Storage	Merlen	Murgtal, Merlen	SG	0.40
	Klusi	Erlenbach	BE	1.30
	Isch	Grindelwald	BE	1.40
	Campocologno 2	Campocologno	GR	1.50
	Sella	Motti della Bolla	TI	1.85
	Wasserauen	Rässenaueli	AI	2.50
	Muttsee	Linthal, Ochsenstafel	GL	4.00
	Ganterbrücke	Ried-Brig	VS	5.00
	Fully	Fully	VS	5.00
	Diablerets	Les Diablerets, Le Plan	VD	5.20
	Oberrickenbach	Oberrickenbach	NW	6.80
	Cavaglia	Poschiavo, Cavaglia	GR	7.30
	Vouvry	Vouvry, Haut du Village	VS	7.50
	Engelberg	Engelberg	OW	8.40
	Kaiserstuhl	Kaiserstuhl	OW	9.00
	Altstafel	Ulrichen, Altstafel	VS	9.20
	Fuhren	Underi-Furen	BE	9.85
	Tremorgio	Rodi-Fiesso	TI	10.00
	Palü	Poschiavo, Alpe Palü	GR	10.00

Source: (BFE, 2011g)

I. Sources for the S&P/S-SHP potential evaluation of the reference types in the Canton of Valais

Table: Sources for the potential evaluation of the reference types in the Canton of Valais

Reference type name	Sources for the potential evaluation VS
SHP plant	- Based on the Swiss hydropower database for plants above 300 kW (BFE, 2011g), all plants are evaluated on Google-earth and Swiss maps. - Survey with all SHP plants which got the FIR in 2010 (Manser, 2011). - Contacting the electricity producers: interview list in Table 1-2, and FMV, Alpiq, Romande Energie, Synergy, Augstbord Energie SA, Arg SA. - Reports on small storage plants (Berthod and Droz, 2005).
Lake	- Database from the authorities (Berthod and Droz, 2005). - Google-earth and Swiss maps.
Flood protection infrastructure	- Database from the authorities (Meetings with Service de l'énergie, Canton du Valais). - Reports on weirs (Berthod and Droz, 2005).
Artificial snow making infrastructure	- Contacting the ski stations: Bellalp, Montana, Saas-Fee, Verbier, Zermatt - Database of storage facilities for artificial snow making reservoirs from the Cantonal authorities (Berthod and Droz, 2005).
Irrigation infrastructure	- Database of irrigation reservoirs from the Cantonal authorities (Berthod and Droz, 2005). - Contacting the communes based on the database: Arbaz, Savièse
Drinking water infrastructure	- Database from previous research (Blueark). - Contacting the communes based on qualitative research (interviews and meetings in the Canton).
Unused military infrastructure	- Contacting the military department: Meetings with armasuisse and questionnaire sent to the caretakers of armasuisse infrastructure in the Valais.
Inoperative gallery	- Contacting the owners of large scale hydropower plants: FMV, BKW, Alpiq, Romande Energie, EnAlpin, expert advice (LCH-EPFL).

J. Hypothesis in the potential evaluation tool

Description	**Quantité**	**Unité**	**Commentaire / Source**
Hypothèse de base : heure de pompage	3-5	h/jour	Avec max. 2 cycles journalier. Confirmer par électriciens. Changera probablement dans des réseaux smart grid (plus de cycles possibles).
Techniques			
Altitude Centrale		m	Hypothèse: Centrale à la même altitude que réservoir aval
Facteur de correction sur longueur de la conduite entre réservoirs amont - aval	1.5	-	
Rendement turbine	90%	-	Hypothèse: admis constant; entre 89-94% (Mhylab)
Rendement générateur	96%	-	>92% (Mhylab)
Rendement transformateur	98%	-	>97% (Mhylab)
Facteur de disponibilité	95%	-	
Rendement pompe	85%	-	Hypothèse: admis constant
Rendement moteur	97%	-	Hypothèse: admis constant
Rendement pompe auxiliaire	85%	-	Hypothèse: admis constant
Rendement moteur auxiliaire	97%	-	Hypothèse: admis constant
Rendement transformateur auxiliaire	99%	-	Hypothèse: admis constant
Facteur de disponibilité auxiliaire	95%	-	
Durée de fin d'été	125	jour	
Durée de l'hiver	150	jour	
Durée de la fonde des neiges	90	jour	
Les cycles évalués sont journaliers (ex. pompage-turbinage sur une journée)			
Economiques			
Ratio d'endettement	60%	-	Manser 2011
Durée de l'amortissement	25	an	Durée RPC de 25 ans
Taux de rentabilité capital	8%	-	EVU Partners 2011, Manser 2011
Taux d'intérêt	5%	-	Entre 4-8% (Leutwiler 2011)
Inflation	1%	-	BFS, 2011
Durée de l'installation	50	an	Leutwiler 2011
TVA	8%	-	
Coûts conception, ingénierie, suivi	5%	-	Mhylab a 10% pour ingénierie, diverse, imprévus
Coûts installation de chantier et frais généraux entreprise	5%	-	

Coûts administratifs	2%	-	
Coûts imprévus	10%	-	
Coûts annuel:			2 cts/kWh comme ordre de grandeur
Maintenance génie civil	1.0%	-	de l'investissement en question
Maintenance électromécanique	2.5%	-	de l'investissement en question; y.c. changement des turbines
Maintenance de la conduite	0.8%	-	de l'investissement en question
Assurances et frais admin.	0.4%	-	de l'investissement total
Si ouvrage à buts multiples, alors modifier manuellement la répartition des coûts dans les calculs économiques.			

K. Economic formulas in the potential evaluation tool

Calculs économiques

Coûts d'investissement					
Partie de l'ouvrage	**En fonction de:**	**Formule coûts [CHF]**	**Source**	**Source contrôle**	**Commentaire**
Prise d'eau	Débit installé Q [m^3/s]	IF(Q<1;(-0.1111*Q*Q+0.3222*Q-0.0111)*1000000*0.164;(-0.00001*Q*Q*Q-0.0012*Q*Q+0.0772*Q+0.2049)*1000000*0.164))	SMART 2010	POPEHYE (EPFL)	
Barrage / Digue	Volume de barrage et matériau [m^3]	Volume * CHF/m^3 depending on the material	POPEYHE (EPFL)		
Dessableur	Débit installé Q [m^3/s]	Calculé avec POPEHYE	POPEYHE (EPFL)		
Passe à poisson simple	Forfait	30’000			
Passe à poisson moyen	Forfait	50’000			
Passe à poisson difficile	Forfait	100’000			
Réservoir amont	Volume réservoir [m^3]	Volume * 50 CHF/m^3			
Réservoir aval	Volume réservoir [m^3]	Volume * 50 CHF/m^3			
Réservoir auxiliaire	Volume réservoir [m^3]	Volume * 50 CHF/m^3			
Conduite	Diamètre D [mm], Distance entre les réservoirs (/centrale) L [km]	L*((0.0012*D*D+0.1888*D+16.122)+(280*((D/1000)^2)+370*D/1000+168.2))	TURBEAU (EPFL)	POPEHYE (EPFL)	Alternative de source: SMART 2010
Conduite auxiliaire	Diamètre D [mm], Distance entre les réservoirs L [km]	L*((0.0012*D*D+0.1888*D+16.122)+(280*((D/1000)^2)+370*D/1000+168.2))	TURBEAU (EPFL)	POPEHYE (EPFL)	Alternative de source: SMART 2011
Turbine-Alternateur	Puissance hydraulique P [kW]	-20000+350*(P-5)+2000*((P-5)^0.5)+55000*((P-5)^0.333333333)	Blueark	SMART 2010	Check: TURBEAU
Pompe-Moteur	60% Turbine-Alternateur	60% de coûts turbine-alternateur	LMH		
Cellule de coupure, Télémaintenance, Control	Constant	200’000	TURBEAU (EPFL)	SMART 2010	
Transformateur	Constant	100’000	Blueark	SMART 2010	
Centrale	Puissance hydraulique P [kW]	900*P+200000-(coûts turbine-alternateur, control, transformateur)*0.9	POPEHYE (EPFL), adapter pour exclure électromécanique		
Accès au Réservoir amont (route)	Distance de la route [m]	200'000 * dist	POPEHYE (EPFL)	SMART 2010, TURBEAU (EPFL)	
Accès au Réservoir aval (route)	Distance de la route [m]	200'000 * dist	POPEHYE (EPFL)	SMART 2010, TURBEAU (EPFL)	

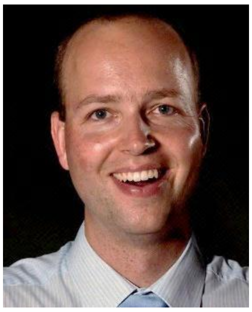
Accès au Réservoir auxiliare (route)	Distance de la route [m]	200'000 * dist	POPEHYE (EPFL)	SMART 2010, TURBEAU (EPFL)	
Conntection au réseau électrique	Distance du réseau [m]	30000+90'000*dist	TURBEAU (EPFL)	Blueark	
Coûts conception, ingénieurie, suivi	Coûts construction	5% des coûts de construction	Blueark	RETScreen	
Coûts installation de chantier et frais généraux entreprise	Coûts construction	5% des coûts de construction	Blueark	TURBEAU (EPFL)	
Coûts administratifs	Coûts construction	2% des coûts de construction	Blueark		
Coûts imprévus	Coûts construction	10% des coûts de construction	Standard		
TVA	Investissement	8% de l'investissement			
Coûts d'exploitation (annuel)					
Maintenance génie civil	de l'investissement en question	1% des coûts d'investissement en génie civil (sans la conduite)	Blueark	Leutwiler 2011: 0.8-1.5%	
Maintenance électromécanique	de l'investissement en question; y.c. changement des turbines	2.5% des coûts d'investissement électromécanique	Blueark	Leutwiler 2011: 2.5%	
Maintenance de la conduite	de l'investissement en question	0.8% des coûts d'investissement de la conduite	Blueark		
Assurances et frais admin.	de l'investissement total	0.4% des coûts d'investissement totaux	Blueark		
		TOT	(Approx.: 2ct/kWh)		

L. Digital appendix

1. **List of SHP plants in the Canton of Valais** (can be ordered from the author)
2. **Marktführer: SHP equipment and construction business in Switzerland**: download under http://www.iskb.ch/marktfuehrer-kleinkraftwerke/
3. **Details of the FIR scheme** (can be ordered from the author)
4. **Potential evaluation tool** (can be ordered from the author)
5. **Detailed evaluation of the Canton of Valais** (can be ordered from the author)
6. **Detailed evaluation of the Reference type "SHP plant" in the Canton of Valais** (can be ordered from the author)
7. **Extrapolation of the results of the Canton of Valais to whole Switzerland** (can be ordered from the author)
8. **Papers**: download under http://infoscience.epfl.ch/ (Crettenand Nicolas)

M. CV

Nicolas Crettenand



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30 April 1980
Swiss
Married, 1 child

EMPLOYMENT EXPERIENCE

- **PhD candidate – Ecole polytechnique fédérale de Lausanne (EPFL)** **Switzerland** **Jan 09 - today**
  - ✓ PhD research on the facilitation of mini and small hydropower in Switzerland through policy instruments, by taking into account the current liberalisation of the electricity sector, the post-Kyoto discussions and the government's aim to increase the importance of renewable energy sources. With a particular focus on storage and pumped-storage schemes. http://mir.epfl.ch/page-21522-en.html
  - ✓ Theoretical development on the co-evolution and coherence between institutions and technologies in network industries at the Chair MIR (http://mir.epfl.ch/page-21526-en.html).
  - ✓ Research projects with the Energy Center (http://energycenter.epfl.ch).
- **Member of the Swiss Humanitarian Aid Unit (SHA)** www.skh.ch **Switzerland** **Sep 08 - today**
  - ✓ Member of the Water and Environmental Sanitation expert group (WES)
  - ✓ Member of the Construction expert group / Structural Engineer within the Swiss Rescue Chain
- **Project Manager – MEDAIR, Antananarivo/Maroantsetra** www.medair.org **Madagascar** **Mar 10 - Apr 10**
  - ✓ Design of a WASH project proposal - the continuation of a project started in 2007
  - ✓ Design of a second phase DRR project proposal - the continuation of a project started in 2007
- **Engineer, Dam department – STUCKY Ltd, Renens** www.stucky.ch **Switzerland** **Nov 07 - Dec 08**
  - ✓ Preliminary and feasibility studies for mini and small hydropower projects.
  - ✓ Tender documents for river embankment reinforcing project.
  - ✓ Tender documents for dam heightening projects in Switzerland.
  - ✓ Dam safety annual report.
- **Project Manager – MEDAIR, Antananarivo** www.medair.org **Madagascar** **Feb 07 – Apr 07**
  - ✓ Development of a strong cyclone response capacity in the WASH sector in Antananarivo's IDP camps.
  - ✓ Reduction of epidemic risk by improvement of access to hygienic latrines and drinking water.
  - ✓ Follow-up of Red Cross IDP kit distribution and hygiene promotion volunteers.
- **WASH Manager – MEDAIR, Maroantsetra** www.medair.org **Madagascar** **Oct 06 - Oct 07**
  - ✓ Water transfer by gravity system (preliminary studies, feasibility studies, tender documents, construction supervision and assessment).
  - ✓ Follow-up of manual pumps construction, disinfection and adjustment of existing water points to the sanitation standards.
  - ✓ Technical and organisational support to the commune of Maroantsetra (20'000 habitants).
  - ✓ Participation in the development and implementation of capacity building tools.
  - ✓ Emergency project – restoration of access to drinking water, rehabilitation of sewage channels, rehabilitation and construction of bridges, support to local authorities in disaster management and delegation to emergency coordination office in Antananarivo.
- **Co-founder and president – GUINKOUMA** www.guinkouma.org **Burkina Faso** **Jan 00 – today**
  - ✓ Construction of a school complex, water supply and primary health care centre in Ouagadougou (primary, secondary and vocational school; 2'000 pupils today). Local initiative (Groupe Scolaire Guinkouma) and support from Switzerland (Association Guinkouma).
  - ✓ In Burkina Faso, strategic planning, technical advice, site visits, liaison with local authorities
  - ✓ In Switzerland, project coordination, budgeting and finance supervision, quarterly meeting of the board, newsletter, fund-raising

EDUCATION & QUALIFICATIONS

- 2001 - 2006 MSc Civil Engineering (with focus on water and energy), Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland, http://enac.epfl.ch/
- 2004 - 2005 Minor in Management of Technology & Entrepreneurship, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland, http://mtei.epfl.ch/
- 1995 - 2000 Scientific Matura, Gymnasium Neufeld, Bern, Switzerland

Nicolas Crettenand

ADDITIONAL TRAININGS

2011 (Aug)	SHA WES Rapid mapping course – SHA, Switzerland – introduction and training on rapid mapping tools
2011 (Feb)	SHA On-site advisor course for SwissRescue – SHA, Switzerland – assessment of buildings, field exercise, GPS and radio training, HazMat training
2010 (Nov)	Children and Dealing with the Past Course – SwissPeace / KOFF, Switzerland – effects of the experience of past adversities, losses and trauma, grief process at the individual and community level, examples of programs
2010 (Sep)	SHA WES course – SHA, Switzerland - assessing water quality in emergency situations course (laboratory, well cleaning, chlorination)
2009 (Apr)	SHA Structural engineer course for SwissRescue – SHA, Switzerland – introduction course for Structural Engineers
2009 (Mar)	SHA Construction course – SHA, Switzerland – urban planning, earthquake resilience, WASH in site planning, reconstruction/rehabilitation
2008 (Nov)	UN INSARAG certification as structural engineer with SwissRescue – SHA, Switzerland – advising Management and Search and Rescue teams concerning safety. First assessment on rehabilitation and reconstruction measures.

MAIN PUBLICATIONS

Crettenand, N. (2012) Small hydro - Storage and pumped-storage plants in Switzerland. International Water Power and Dam Construction, April 2012.

Crettenand, N. (2011) Pump-storage small hydropower as an example of co-evolution between institutions and technologies. Fourth Annual Conference on Competition and Regulation in Network Industries. Brussels, Belgium.

Crettenand, N. (2011) *Small hydropower - the potential of storage and pump-storage schemes in Switzerland*. HYDRO 2011. Prague, Czech Republic.

Crettenand, N., Denis, V. (2011) *Small hydropower storage and pump-storage schemes for decentralised energy supply*. Renewable Energy Word - Europe Conference. Milano, Italy.

Crettenand, N., Denis, V., Choulot, A. (2011) *Small hydropower in Switzerland: Challenges and Opportunities*. International Water Power and Dam Construction – Yearbook 2011.

Finger, M., Crettenand, N., et al. (2010) *Governing the dynamics of the network industries*. Discussion paper series on the coherence between institutions and technologies in infrastructures 2010.

Crettenand, N., Laperrouza, M., Finger, M., Duthaler, C. (2010) *Performance and Coherence in Network Industries*. Third Annual Conference on Competition and Regulation in Network Industries. Brussels, Belgium.

Crettenand, N., Finger, M. (2010) *The facilitation of mini and small hydropower in Switzerland through institutional mechanisms*. EEM10 - 7th International Conference on the European Energy Market. Madrid, Spain.

Crettenand, N. (2010) *The facilitation of small hydropower in Switzerland: shaping the institutional framework*. Hidroenergia 2010 - International Congress and Exhibition on Small Hydropower. Lausanne, Switzerland.

Crettenand, N., Hemund, C. (2010) *The facilitation of mini and small hydropower through institutional mechanisms for development*. EPFL - UNESCO Chair: International Scientific Conference on Technologies for Development. Lausanne, Switzerland.

Moser, R., Crettenand, N., et al. (2006) *Numerical and Experimental Study of a Low Cost Drip Irrigation System in Burkina Faso*. EPFL-ENAC-LCH Working Paper.

Crettenand, N. (2006) *Business plan for Chalberhöni mini hydropower project*. EPFL-ENAC-LCH Master project.

Crettenand, N. (2006) *General considerations about the development of mini hydropower in an international context*. EPFL-ENAC-LCH Master project.

Crettenand, N., Finger, M., Dubas, A. (2005) *What works and what doesn't with BOT contracts?* The case of thermal and hydraulic plants. EPFL-CDM-MIR Working Paper.

LANGUAGE AND COMPUTER SKILLS

- Language — French and Swiss German – mother tongues; English and German – fluent; Spanish – basic
- Computer — Excellent working knowledge of Microsoft Word, Excel, Powerpoint, experience with MS Projects, AutoCad and rapid mapping

INTERESTS

- Time with family and friends, exploring new countries, beach volley, reading Jeune Afrique

Date and Place: 02.04.2012, Lausanne – Switzerland